The
ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XX No. 6 JUNE, 1959

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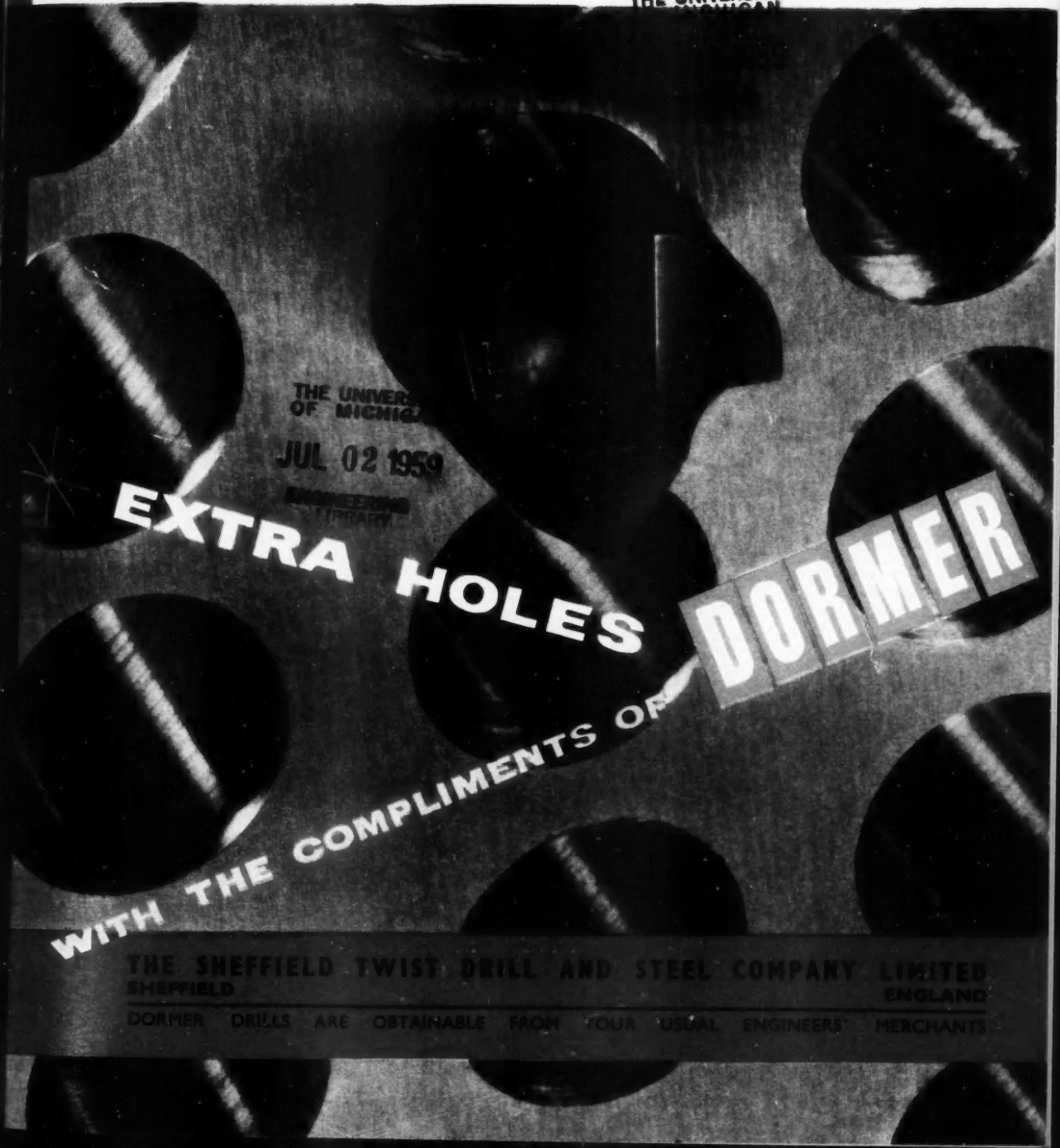

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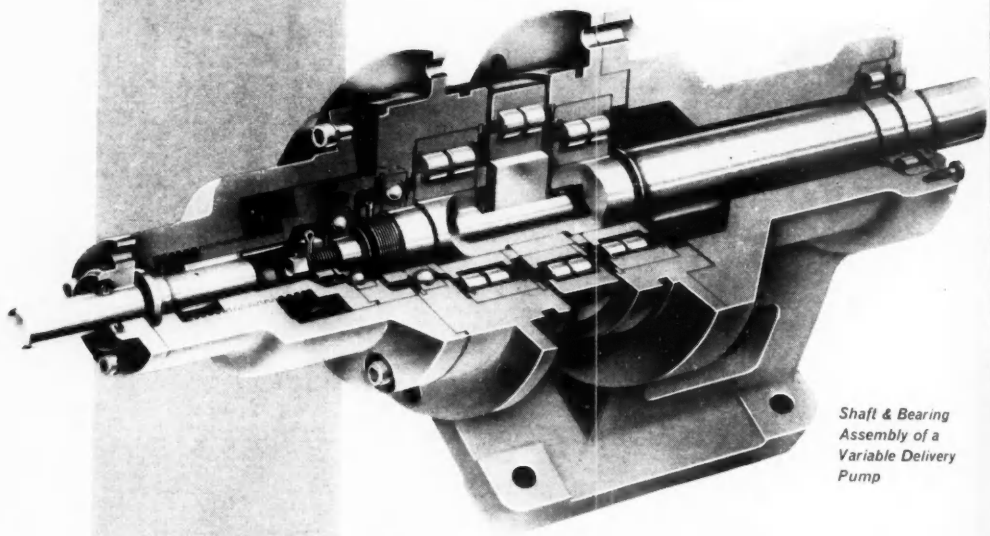

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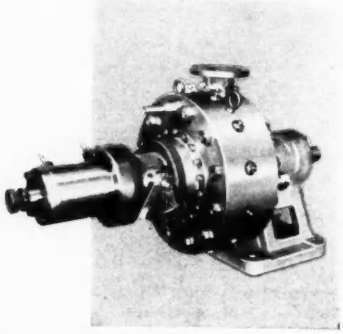

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CONTENTS

	Page
The Minidigest	A2
The Blue Pages	231
The Design and Potentialities of Fuel Cells	235
The Use of Resilient Mountings for Reducing Structure-Borne Noise	237
Heat Treatment of Sintered-Iron Parts	239
Radioactive Methods of Determining the Influence of Viscosity on Lubricant Film Thickness	241
Investigations into Techniques for Producing Cast Silicon Components	243
The Effect of Shot-Peening on the Fatigue Strength of Metals	245
Improved Hot-Gas Engine, using a Rhombic Drive Mechanism	247
Designing Bimetal Elements for Maximum Performance	252
Ultrasonic Machining of Hard and Brittle Materials	255
British Industrial Developments	257
Additional Abstracts	260
New Materials, Processes, and Equipment	262
News of the Month	265
New Technical Books	269
Latest Industrial Literature	270

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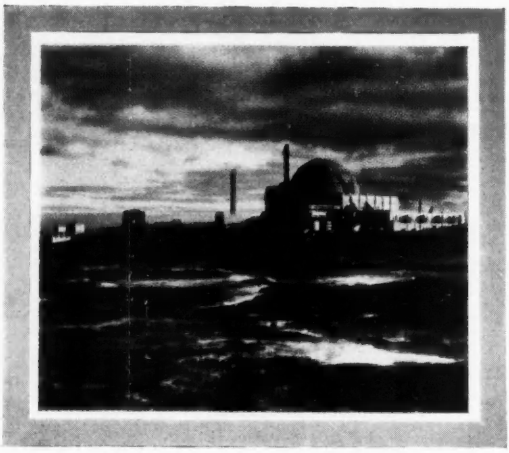

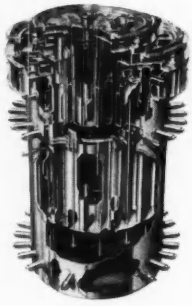

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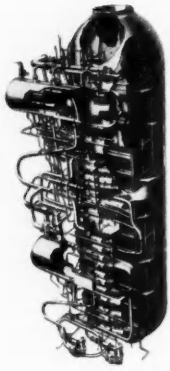

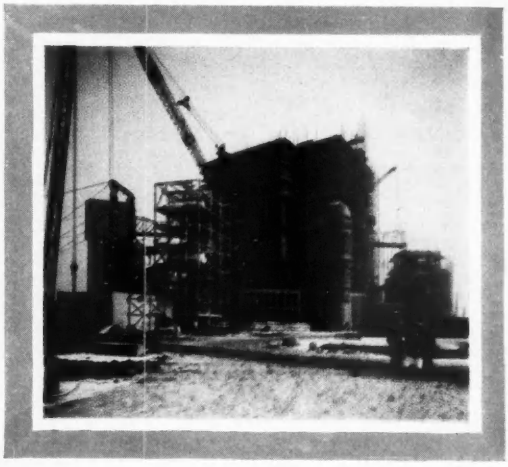

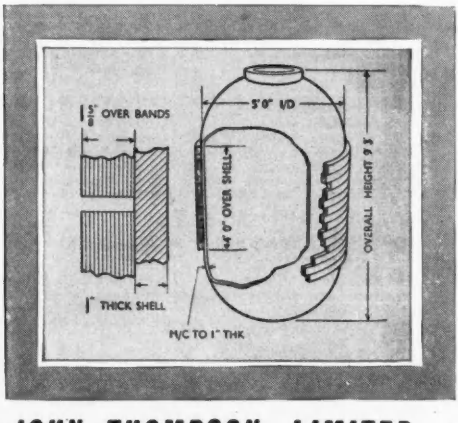

LAYER VESSELS

The development of large pressure vessels is limited by the difficulty of site fabrication and testing of plates thicker than 3 to 4 inches. This matter had become particularly urgent with the increasing demands for plant working at higher pressures.

The band reinforced vessel which makes use of thinner plate is a solution to this problem. A cylindrical shell with hemispherical ends is reinforced with bands of multilayer thin plate. This diagram shows the way in which the bands are built up and positioned on the vessel. John Thompson have carried out full scale tests and developed a satisfactory technique for the erection of these layer vessels on site.

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A.26

THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

• *ELECTROLYTIC COATING OF METALS WITH PLATINUM*

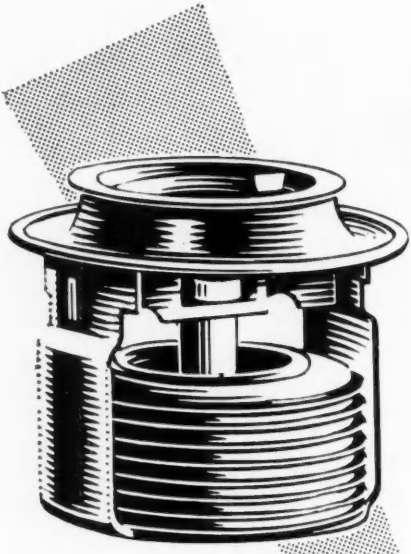
When platinizing metals, especially molybdenum, by conventional methods involving deposition of the platinum in the form of a platinum-black layer which is then sintered by heating to about 1000°C and converted into platinum, difficulties are often encountered with regard to obtaining satisfactorily adherent layers of pure platinum. Furthermore, it is usually very difficult to remove completely foreign metals which are also deposited, especially if the platinum layer has a comparatively large thickness. However, according to a recently patented process, these and other difficulties can be overcome if the platinum, in the form of a platinum-black layer, is deposited from an electrolyte made up of an aqueous solution of from 150 to 300 grams per litre of chloroplatinic acid and from 1 to 15 grams per litre of mercuric chloride, the current density being from 50 to 150 A/dm². The layer is then sintered at, say, 1000°C to convert the platinum-black to platinum, and it has been found that the mercury deposited simultaneously with the platinum-black evaporates almost completely from the layer during sintering. This process makes it possible to apply platinum layers of any arbitrary total thickness, without any tendency to blister or become porous or to contain mercury or other foreign metals. Moreover, since the mercury compound greatly increases the output of the bath, a layer of any given thickness is deposited comparatively quickly. For producing a thick layer, it has been found advantageous to apply a successive number of platinum layers, each of from about 0·5 to 2 microns in thickness, so that, in fact, the object is electrolytically coated and heated several times. When coating molybdenum, the first platinum layer should be between 0·5 and 0·7 micron in thickness; otherwise, there is a risk that the layer may show signs of cracking after sintering. However, after production of the first layer, the second layer can be of any desired thickness.

• *COLD-CATHODE RADIO VALVES*

Believed to be the first major break-through in basic thermionic valve design, a radically new radio valve, utilizing a cold cathode, has recently been developed in the U.S.A. and may well prove to be the forerunner of a new series of general-purpose valves for military and civilian use. As distinct from conventional thermionic valves, which require a red-hot cathode element, consuming appreciable power and obliging the use of more complicated circuits or extra batteries, the new valve replaces the hot element by a cold cathode, which comprises a tiny nickel cylinder specially coated with porous magnesium oxide. A high-voltage field causes electron flow, which in turn produces a characteristic phosphorescent blue glow in the valve. Like other electronic valves, the new valve is extremely resistant to heat and atomic radiation, but has the added advantage of far greater life, so much so that it should outlast any equipment in which it is installed. In addition, the new valve becomes operational immediately after the current is switched on, whereas conventional valves require several seconds for warming up, while current consumption is estimated to be less than 10% that of a comparable hot-cathode valve. The cold-cathode principle is believed to be adaptable to nearly all types of electronic valves, including television screens and giant radar and transmitting valves, as well as to nearly all general-purpose radio valves. It is also considered feasible to construct miniature and sub-miniature valves on this principle which would compare favourably with transistors in size. Other applications envisaged include the development of smaller and more efficient walkie-talkie sets and simplified communications equipment for use where the heat generated by conventional hot-cathode valves gives rise to serious problems.

• *PRODUCTION OF INTERNAL SURFACE LAYERS ON STEEL*

Owing to the great stresses to which gun barrels are subjected as a result of corrosion, erosion, etc., their internal surfaces are quickly attacked and destroyed, while repeated firing causes considerable wear, necessitating their replacement after a comparatively short period. Various methods have been proposed for avoiding these difficulties, but none has proved really satisfactory. A recently patented process, however, is intended to improve the surface resistance of iron and steel tubes, especially gun barrels, by ion bombardment of their internal surfaces in a glow discharge, using ions of carbon, silicon, or hydrogen, alone or in combination with one another or with nitrogen, the ions being produced by the glow discharge in a gas-



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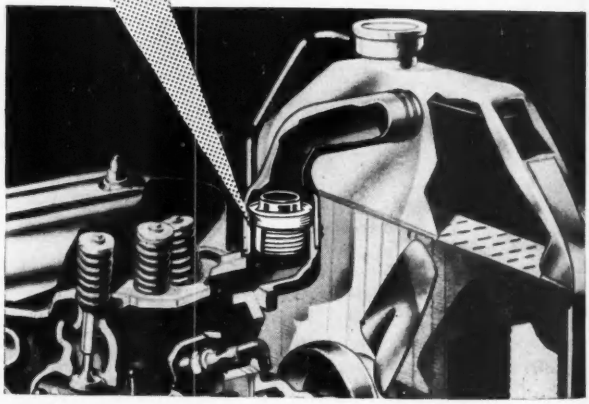

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eous atmosphere. In order to produce the discharge in the interior of the tube, the tube can be arranged vertically in a gas-discharge chamber and connected to the negative pole of a source of d.c. supply of from 400 to 600 V and capable of applying from 3 to 10 kW, the positive pole comprising a wire disposed along the axis of the tube. As the processing atmosphere, use is made of a gas containing nitrogen, previously purified by means of ferrosilicon at a high temperature. Thus, for example, a mixture of nitrogen and hydrogen, or ammonia enriched with nitrogen or diluted with hydrogen or with a rare gas, is suitable for the purpose. In operation, the pressure of the nitrogen-containing gas introduced into the gas-discharge chamber is adjusted to between 1 and 10 mm Hg, so that the tube assumes a temperature suitable for hardening by nitriding, i.e., between 500 and 550°C, the duration of the treatment depending on the desired depth of nitriding and varying from 12 to 30 hr. In this way, it is possible to obtain, in addition to other advantages, a much more rapid depth of penetration than has hitherto been possible with other methods.

● *METHOD OF DEPOSITING METALLIC COATS ON GLASS FIBRE*

A method has been developed for the deposition of metallic coats on strands of glass fibre, especially on rovings, which generally consist of a number of untwisted strands, each comprising a very large number of glass filaments. As an example, one roving may contain eight strands, each consisting of 204 closely associated filaments, representing 1632 filaments of about 10 microns each in diameter. Owing to this very large number of filaments in close contact with each other, the application of metallic coatings to rovings is of considerable difficulty, particularly where the metallic coating is to serve as electrical conductor, as even slight discontinuities in the coating will materially increase electrical resistance. The new process combines the use of a suitable metal-bearing gaseous compound capable of being decomposed by heat and means for vibrating the rovings. Typical gaseous compounds include nickel carbonyl, copper acetyl acetonate, molybdenum carbonyl, and chromium hexacarbonyl, in which the glass rovings are heated in a processing chamber to the temperature at which decomposition of the gas occurs and are simultaneously vibrated at a frequency between 9 and 25 cps. The vibratory movement, which is preferably obtained by drawing the material through the chamber in a slightly taut condition and then applying a repetitive impulse, spreads the filaments and permits the gas to contact the filament surface intimately and uniformly. When the vibratory movement is removed, the filaments readily compact and the strands return substantially to their original state. The speed of drawing through the chamber is affected by various factors, such as the concentration of the gas and the temperature of the roving, but it may be said that a drawing speed of up to 300 fpm is attainable. Plating conditions are not in themselves critical, but it is, of course, essential that the roving be heated to at least the minimum temperature of the gas used. Also, it is desirable that the gas flows in countercurrent to the moving roving, to ensure that it receives a slight coating of metal before much cooling occurs, facilitating further deposition. However, this factor is considered important only where operational factors, particularly temperature, approach marginal conditions.

● *FLUORESCENT LAMPS FOR USE IN STANDARD LIGHT SOCKETS*

Eliminating the need for the conventional external ballasts and the fixtures required to conceal them, a newly developed fluorescent lamp requires no external ballast or starter and can be plugged in to a standard light socket, making it possible to use either an incandescent or a fluorescent lamp in the same fixture. The new self-ballasted lamp contains a built-in bimetal starting switch, similar to that used in a conventional fluorescent-lamp starter, and an incandescent tungsten filament in place of the external inductor ballast. The filament adds to the total lumen output of the lamp, but it is stated that its colour constitutes an overall colour-improving factor, the red end of the spectrum common to incandescent lamps augmenting the normal blue-green end of the spectrum associated with fluorescent lamps. Although the lamp has the advantage that it can be made with a single base for fitting to a standard socket, it can also be supplied as a conventional double-ended unit. In addition, it can be made in various decorative shapes, so that, in effect, it can become a fixture, as well as a light source. As yet, the lamp is not being manufactured commercially, but laboratory tests indicate that it combines high efficiency with reliable operation.

● *SPRAY-FORMED CERMET PARTS*

Cermet parts are usually made by conventional powder-metallurgy techniques, in which the cermet powder is press-formed in a die, ejected, and then sintered, but the limited size of the dies and presses normally available places a severe restriction on the dimensions and shape of the parts that can be produced. Thus, although the high melting point and excellent oxidation resistance of some cermets are especially valuable for parts such as linings for combustion chambers, jet exhausts, rocket nozzles, and nose cones of missiles, these parts are far

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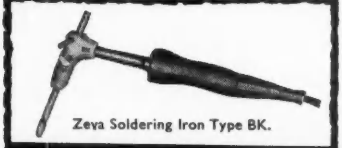

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too large or complicated to be made by ordinary powder-metallurgy methods. To overcome these difficulties, a new technique has been developed in which spray-formed cermet parts are produced by building up coatings on an expendable pattern to almost any size or shape, the pattern being removed by chemical or other means when spraying is completed. In this way, parts such as large tubes with varying wall thickness, flat radiation shields, and large conical shapes can be made from molybdenum disilicide, chromium carbide, chromium-nickel boride, tungsten-carbon and tungsten-boron compounds, nickel and molybdenum aluminide, etc. The relative density of the parts produced varies from 82 to 90%, depending on the material used, but desired densities as high as 95% can be obtained by sintering at 2000 to 2500°F, as in the case of powder metallurgy. It is expected that spray-forming will be used instead of standard techniques for forming difficult shapes, and will supplement the slip-casting method recently developed for producing cermet and refractory hard-metal parts.

● *PRODUCTION OF SUBSTANCES OF HIGH MOLECULAR WEIGHT*

A recently patented method of producing substances of high molecular weight consists of bringing a polymerizable organic liquid into a state of dispersion, so that it presents a large surface area, and then exposing it to the radiation of charged particles. For this purpose, the liquid may be sprayed to produce droplets in a gas, but it is also possible to irradiate the liquid in the form of very thin self-supporting films, or films which adhere to a thin metal net. The solid substance produced, which is of high molecular weight, can then be separated from the liquid. It is also possible to produce by this method liquids of any desired viscosity. Under certain conditions it may be advantageous to withdraw unpolymerized liquid from the processing chamber and to repeat the process of withdrawing and irradiating several times. It may also be advantageous to effect, by electrical means, longitudinal alignment of the substance of high molecular weight in the liquid and expose it to irradiation in this condition. These substances arise in the form of molecules which are more extended in one direction than in the other and are termed "oblong molecules"; they are charged in the electric field by electrostatic induction, so that they form dipoles which align in the field. In this way, a preferred orientation of the substance produced can be achieved, though it is claimed that, while irradiation with electrons is particularly advantageous, any other kind of corpuscular radiation may be used. The irradiation process can be carried out in vessels held at sub-atmospheric pressures, e.g., from 10^{-3} to 10^{-5} mm Hg, but atmospheric pressure or pressures higher than atmospheric can also be employed. In this connection, sub-atmospheric pressures are particularly suitable for the irradiation of liquids which do not contain any nuclei of solid substances, in order to initiate the formation of such nuclei, whereas increasing pressures are indicated when the concentration and average size of the nuclei increase.

● *TEST FOR SUSCEPTIBILITY OF ALLOYS TO HOT-CRACKING*

Hot-cracking during welding has received much attention because of the need for avoiding defects in the welded joints of heavy-walled austenitic stainless-steel piping for steam power plant and in components of nuclear power plants. Since attempts to predict weldability from chemical analysis have been singularly unsuccessful, the behaviour of an alloy must be established by welding it under conditions closely approximating those encountered in practice, and many types of tests have been developed in an attempt to simplify the problem of predicting shop performance from laboratory experiments. However, all known tests for hot-cracking are slow and expensive, and require relatively large amounts of metal for a welding base and the processing of materials into electrode wire. Some require elaborate equipment for operation, and most are subject to the variables associated with hand welding. To overcome these limitations a new test has been developed which should prove highly valuable for determining the susceptibility of alloys to hot-cracking, such as might occur during the freezing of a weld bead or solidification of a casting. In this new test, a small sample is levitation-melted in an inert atmosphere and is then cast in the shape of tapered pins in a series of copper moulds. Restraints at the ends of the pin impose tensile stresses on the sample as the mould expands and as the casting solidifies and contracts. The geometry of the mould that will produce a certain amount of hot-cracking provides a means of classifying alloys in order or merit. The test is quick and inexpensive; furthermore, it is applicable both to the evaluation of existing materials and to studies of the effects of alloying additions and impurities on hot-cracking.

● *ELECTRICAL PYROMETERS FOR INDICATING TEMPERATURE DIFFERENCES*

Particularly suitable for indicating the temperature of a body with a small surface area, such as wire or strip, a new type of electrical pyrometer is designed to furnish continuous indications of temperature differences between two or more hot bodies, or of temperature changes at different regions in a body. The new pyrometer incorporates an element which is res-

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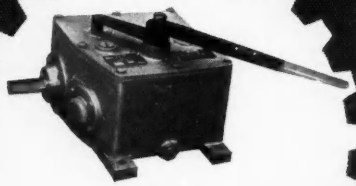

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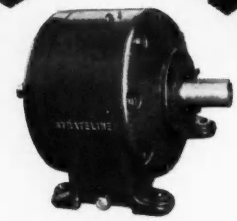

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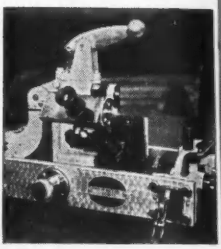

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ponsive to radiant heat, such as a lead sulphide cell, enclosed in a casing fitted with a narrow window for restricting the energy received by the cell to a small solid angle and, if required, with a lens system for focusing the radiant energy onto the cell. The cell casing is mounted on a pivot in such a way that it can be oscillated about the mounting for scanning the surface of the body. The pyrometer is used in conjunction with a cathode-ray tube whose beam is so deflected along one axis that the position of the beam on the screen corresponds with the region scanned by the pyrometer. In cases where it is desired to indicate the temperature difference between two bodies, one of which may represent a standard maintained at a predetermined temperature, the pyrometer is directed successively towards both bodies, and the temperature difference is indicated by the deflection of the beam on the screen on the cathode-ray tube. It should be appreciated that the voltage output of a lead sulphide cell is dependent on such factors as temperature, supply current, and emissivity, so that this type of cell is not suitable for absolute temperature measurements but only for temperature variations. A typical application of this instrument is in the measurement of the temperature distribution along a length of wire during its passage from a heating device to a processing plant, particularly in the case where the temperature of the wire should be maintained at a relatively low value, i.e., of the order of 150°C, making a conventional visual pyrometer unsuitable for indicating temperature variations.

● *INCREASING THE WEAR RESISTANCE OF OILWELL-DRILL PIPE-COUPLINGS*

The couplings used in oilwell strings are subject to a high rate of wear during the drilling of deep oilwells. A rotating drill string may penetrate thousands of feet of sand and rock, and the pipe-couplings, called tool joints, are exposed to particularly severe abrasion, since their diameter is greater than that of the pipe. A new method has now been evolved for hard-surfacing the tool joints by using an automatic, gas-shielded, surface-melting arc and a metered flow of tungsten-carbide particles into the molten pool behind the arc on the rotating tool joint. A non-consumable electrode melts the surface of the tool joint to a depth of about $\frac{1}{8}$ in. In carrying out the process, the tool joints move on a conveyor through an induction heater, which raises their temperature to 750 to 800°F, thus maintaining the original physical properties of the steel through the welding operations. The tool joint is then clamped in a lathe chuck and an arc is struck between the thoriated-tungsten electrode and the joint, helium being used as the shielding gas. As soon as the surface metal melts, the joint is rotated and tungsten carbide particles are supplied from a tube behind the arc. The required width of the treated surface is obtained by lengthwise shifting of the joint. It is claimed that the carbide in the overlay produced is uniformly distributed to achieve most effective wear resistance, and spalling and cracking, as it occurred with other methods, are eliminated. By keeping the carbide particles out of the arc, there is little tungsten-carbide dilution with the base metal of the tool joint. Only tungsten carbide is deposited by the inert-tungsten-arc process, because there is no steel filler metal to melt into the surface of the alloy-steel tool joint and the deposit therefore wholly consists of tungsten carbide.

● *IMPROVED FUSION-ABRADING PROCESS FOR REMOVING SURFACE MATERIAL FROM METALS*

Although the principle of using frictional heat for removing material from a workpiece has already been employed successfully in friction parting discs and fusion bandsaws, recently patented equipment differs from such arrangements in that removal is effected by fusion of the material by the rapid action of friction edges, followed by entraining and projecting the fused material away from the workpiece by centrifugal action. This process, which is suitable for removing surface material from flat or curved metal workpieces, including rods and wires, comprises pressing onto the surface a special rotary power-driven tool which presents one or more narrow friction edges rotating at a high speed and provided with fine teeth. The tool passes over the surface at right angles to the applied pressure, the heat of friction produced causing fusion of the surface to the plastic or liquid state, the fused material then being removed by centrifugal action. In practice, the tool can be equipped with a revolving disc fitted with one or more projecting friction rings of high-strength steel and provided with fine teeth, and the operation can be combined with the use of abrasive particles introduced by a gas or liquid between the surface to be worked and the friction edges. The use of oxygen as a carrier for the abrasive is particularly suitable, as it assists removal of the fused material by causing its combustion. In addition, supplementary heat can be produced by electric arcs between the tool and workpiece. It is stated that, by combining the fusion treatment with the use of an abrasive, any surface irregularities left on the workpiece by the friction rings are removed.

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WORLDWIDE REPRESENTATION

THE ENGINEERS' DIGEST
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Design and Potentialities of Fuel Cells

By E. GORIN and H. L. RECHT. (From *Mechanical Engineering, U.S.A.*, Vol. 81, No. 3, March 1959, pp. 63–65, 4 illustrations)

ALTHOUGH research on fuel cells has been carried out sporadically for almost a century, it is only in recent years that widespread interest has been revived in these devices, mainly because of the potentially higher efficiency that can be achieved by the direct conversion of the thermal energy derived from natural fuels to electrical energy. It should be appreciated that a true fuel cell must operate continuously with a steady and constant output of electrical energy and with a continuous supply of fuel to the negative electrode and of oxidant to the positive electrode.

Only recently have fuel cells been devised which begin to meet this criterion of steady output, and a number of different types have been under development. All cells for which any success has been claimed operate with gaseous fuels, and discussion is limited to these, though interest naturally attaches to the use of solid fuels, particularly coal, which is by far the most abundant fossil fuel for generation of power. Prior gasification of coal can be used to produce fuel gas for use in the fuel cell. This operation can be conducted in integration with the fuel-cell process itself to produce a high potential efficiency for generation of power from coal, as well as from other natural fuels.

There are really two basic types of fuel cells that have been under development, i.e., low- and medium-temperature cells, and so-called high-temperature cells. Low- and medium-temperature cells, which may be said to operate in the range between room temperature and 250°C, are characterized by the fact that high output is achieved only when relatively pure hydrogen is used as the fuel and pure oxygen as the oxidant. The most highly developed cell of this type, devised in England by Bacon, operates at moderately high temperatures and at relatively high pressures of about 600 psi.

These hydrogen-oxygen cells have achieved considerable success in the course of their laboratory development, and are of interest for specialized military and possibly civilian applications. In their present state of development, however, they cannot be regarded seriously as a major power source, because the cost of the fuel and of the oxidant is as great as the cost of power generated directly from natural fuels by more conventional methods. Even the apparent advantage of the fuel cell for generation of power at a high efficiency level tends to disappear with this kind of cell.

The high-temperature fuel cell, under development in various laboratories throughout the world, is characterized by the fact that the operating temperature is principally in the range between 500 and 850°C, that operation is carried out at atmospheric pressure, that air can be used as the oxidant, and that ordinary fuel gases which can be generated directly from coal or other fossil fuels, such as water-gas, can be used. The most extensive work in this field has been carried out in Holland at the University of Amsterdam under Ketelaar. Considerable success has been obtained, and cells have been devised which show steady operation at working temperatures for periods of six months.

In the U.S.A., the Consolidation Coal Company have been working on the development of a high-temperature fuel cell, this work fairly closely paralleling that at Amsterdam. The experimental type of fuel cell used is shown in Fig. 1, and any commercial development that may arise will probably operate on a similar principle.

The fuel cell is composed of two flanges, between which an electronically insulating but electrolytically conducting electrolyte matrix is disposed. This matrix consists of a porous-magnesia refractory, impregnated with a molten carbonate mixture which serves as the electrolyte.

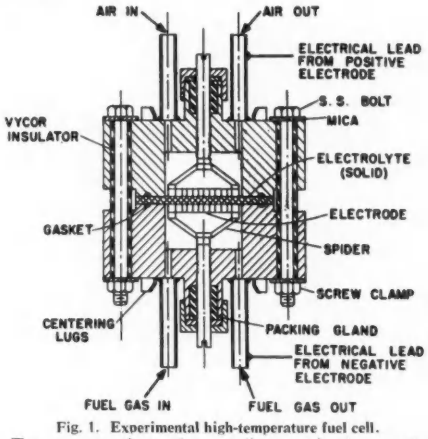

Fig. 1. Experimental high-temperature fuel cell.

Two porous electrodes are disposed in the gas chambers on either side of the electrolyte matrix. Fuel gas is passed in and out of one of these chambers, while air passes in and out through the other chamber. The air electrode is composed either of a porous sintered semiconducting nickel oxide or of silver-wire gauze. Equally good results can be obtained with either. The fuel-gas electrode can be porous sintered-nickel metal, although other materials, such as porous iron, can be used. Fig. 1 illustrates one of the authors' earlier fuel-cell models, but work is now being conducted with pressurized double-porosity-type electrodes, for which much better performance is anticipated.

Good operating characteristics have been attained with these cells, using mixtures of carbon monoxide and carbon dioxide as the fuel gas with an iron-activated fuel electrode. Broers and Ketelaar have obtained very good

performance with a similar system, where the iron activator is backed up with a silver-gauze electrode. The porous-nickel, single-porosity electrode gives fair performance with mixtures of CO and CO_2, as illustrated in Fig. 2, in which cell voltage under steady operating conditions is shown as a function of current density for different CO/CO_2 ratios and temperatures. The theoretical open-circuit voltage for these mixtures is of the order of 1 V.

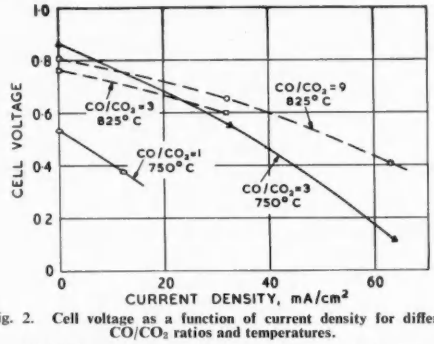

Fig. 2. Cell voltage as a function of current density for different CO/CO_2 ratios and temperatures.

Nickel, however, operates very well as a fuel electrode when hydrogen is present, and Fig. 3 shows similar data on cell operating characteristics at 750°C for a hydrogen-steam mixture as a fuel gas. The open-circuit voltage of the cell changes with current density, owing to the change in gas composition as a result of the cell reaction, and this change has been calculated by means of the Nernst equation. The curve of calculated open-circuit voltage is also given in Fig. 3, the *IR* drop in the cell being the difference in voltage between the two curves. It is found that the *IR* drop is equal to the resistance measured with an a.c. bridge, and it is therefore concluded that the cell operates without polarization with a hydrogen fuel gas. No polarization was observed at the air electrode at current densities up to 125 mA/cm², using either lithiated nickel oxide or silver gauze.

Potentialities of Fuel Cells

Several factors determine the overall economics of the potentialities of a high-temperature fuel system as a source of primary energy. Thus, the fuel cost is a reflection of the thermal efficiency of the cell, while the investment and operating costs must also be considered, these last two costs being very much a function of the cost of the individual fuel-cell elements and of their life. It is difficult, at the present time, to obtain a realistic estimate of the cost of the elements in the fuel cell, since many of the materials are either not manufactured at all or are made on a very small scale. From the authors' work and that of Ketelaar, it would appear that cell life can be of the order of at least six months, but the ultimate life must be longer for such a system to be practical. The cell output per unit of electrode area will also have a great bearing on the economics of the operation of the system.

Both the authors' and Ketelaar's work have also shown that a current output of the order of 30 A/sq ft can be obtained at an operating voltage of 0·75 V, but a detailed theoretical analysis shows that further cell development can yield a current output of 200 A/sq ft at this operating voltage. Such a current output would, if the cell were sufficiently long-lived, approach that required for commercial operation.

An important factor in the fuel cell is the overall thermal efficiency for conversion of the original fossil fuel to electrical energy. An integrated system for effecting this conversion, using either coal or natural gas as fuel, has been proposed and is based on the premise, which has been demonstrated by prior work, that addition of carbon dioxide to the air is necessary to achieve a high-output fuel cell. The high-temperature fuel cell is made up of rectangular elements disposed in parallel, through which the fuel gas is passed countercurrent to the air. An acceptor system is incorporated, which operates countercurrently and adiabatically to effect the transfer of CO_2 from the exhaust gases leaving the cell to the air entering the cell. The cells have re-forming catalysts disposed in the gas channel to convert methane into CO and hydrogen, the heat released during the cell operation being available to carry out this endothermic reaction. The gas leaving the CO_2 acceptor system is rich in hydrogen and may be either simply recirculated where natural gas is used as fuel or passed through a coal hydrogenation or hydro-devolatilization zone to produce the gas required for fuel-cell operation.

An overall analysis has been made for the operation of such a system, based on rather extensive knowledge of the coal hydrogenation-gasification operation and assuming the use of a fuel cell operating at 0·75 V. The electrical efficiency of such a system, using gas produced by hydro-devolatilization of coal, is about 60%, and about 65% with natural gas. With gas obtained from complete coal hydrogenation, the efficiency is about 70%. It should, however, be noted that another system which can be used for complete coal conversion, involving gasification of the coal with steam in an indirect heat-exchange relationship with cell operation, shows a potential electrical efficiency as high as 75%.

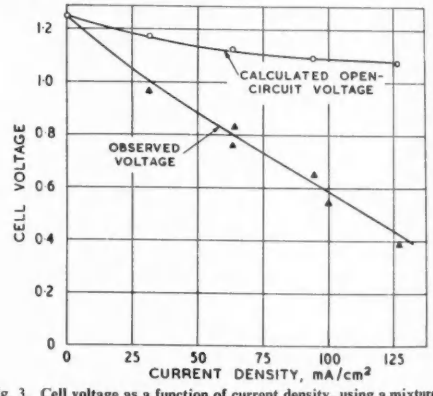

Fig. 3. Cell voltage as a function of current density, using a mixture of hydrogen and steam as the fuel gas at 750°C.

It should be noted that it is possible to make a comparison of the fuel costs that can be achieved by the use of a fuel cell operating at 70% overall thermal efficiency, as compared with fuel costs involved in the generation of nuclear power and by conventional steam plants based on coal. From this comparison, it would appear that the fuel cell would permit coal to remain competitive with nuclear power on the basis of fuel cost over a much longer period than would be the case for a conventional steam plant. Indeed, the indication is that the fuel cell could eventually show a lower fuel cost than a nuclear plant, if located close to the coal mine.

The Use of Resilient Mountings for Reducing Structure-Borne Noise

By J. H. Janssen. (From *De Ingenieur*, Vol. 71, No. 13, March 27, 1959, pp. W71-W78, 10 illustrations)

In many cases, the energy of structure-borne noise is propagated in the form of flexural (i.e., bending) vibrations of plates and beams, the points of maximum deflection being termed antinodes, and those of minimum deflection nodes. Now, the vibrations of a structural component can be transmitted by the movement of these antinodes to surrounding air or water, this being known as radiation. In this way, vibrations of the structural component are converted into audible air-borne noise. Road vehicles and buildings generally have large surfaces which readily radiate noise as a result of high-frequency vibrations generated by a source in their structure. The method of reducing vibrations in the structure differs in each individual case. A high degree of reduction is obtained if the amplitudes are reduced by a factor of 30, but this is usually very difficult to attain, and an amplitude reduction of 10:1 may also be satisfactory.

Acoustic Decoupling

If a source of structural noise acts on an anti-vibration mounting as in Fig. 1, excitation occurs inside the upper mass (denoted by the subscript *i*), which is placed in contact with a flexible element (subscript *v*) through

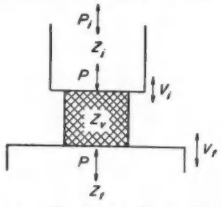

Fig. 1. Principle of vibration transmission through a flexible element.

which the vibrations are not readily transmitted to the lower mass representing the foundation (subscript *f*). In this idealized system, the exciter mass generates an alternating force P_i and has an internal impedance Z_i. If its vibration velocity is v_i, it will exert on the mounting a force $P = P_i - Z_i v_i$. Now, this force P is resisted by the impedance Z_v of the mounting, of which the upper surface vibrates with a velocity v_i, whereas its lower surface has the same vibration velocity v_f as the foundation, so that $P = Z_v(v_i - v_f)$. This force is transmitted to the foundation, which has an impedance Z_f and the velocity v_f already mentioned, so that $P = Z_f v_f$. The object is to make v_f as small as possible.

In acoustics, it is convenient to express velocities in a non-dimensional logarithmic form which relates them to a suitable arbitrary reference value, i.e., $v_0 = 6{\cdot}5 \times 10^{-8}$ metres/sec. The velocity level N_{vel} is then defined as

$$N_{vel} = 20 \log (v/(6{\cdot}5 \times 10^{-8})) \qquad [dB]$$

where v is in metres/sec. In the audible range of frequencies, the velocity level of machine tools, diesel engines, pumps, compressors, generators, and transformers, at the contact surfaces of their anti-vibration mountings, varies from about 90 dB at 45 cps to about 60 dB at 10,000 cps, these being approximate upper limits, the lower limits being about 30 dB below these values. Hydraulic systems have velocity levels varying from about 77 dB at 50 cps to 40 dB at 6000 cps, with somewhat lower levels between 500 and 5000 cps (the curve of the lower limit values is 15 to 20 dB below these values). Water jets give rise to velocity levels ranging from about 80 dB at 100 cps to 55 dB at 400 cps, rising thereafter to 80 dB at 6000 cps. It may be noted that 80 dB corresponds to a vibration velocity of 2×10^{-3} m/sec, 70 dB to 2×10^{-4} m/sec, etc.

For the system represented in Fig. 1, the improvement resulting from the insertion of the flexible member, i.e., the attenuation N_{att} of the vibratory force at the bottom end of the foundation, is given by

$$N_{att} = 20 \log\left[1 + \frac{1/Z_v}{(1/Z_f) + (1/Z_i)}\right] \qquad [dB]$$

The expression in the square brackets is the ratio of the forces with and without the flexible element, and is also equal to the ratio of the velocities occurring at the bottom of the foundation. It can easily be derived from the relations previously given. Another useful criterion is the difference in velocity levels ΔN (in decibels) between the bottom of the upper mass and the top of the foundation, which is regarded as clamped at its bottom end, ΔN being expressed as

$$\Delta N = 20 \log (1 + (Z_f/Z_v)) \qquad [dB]$$

This expression can also be derived from the equations previously given. These two expressions indicate the amount of acoustic decoupling obtained. A low impedance value Z_v for the flexible element is required in both expressions in order to obtain high values of decoupling between the source of structure-borne noise and its foundation.

Noise-Frequency Vibrations in Flexible Elements

If the finite mass of the foundation is denoted by M, then the absolute value of its impedance Z_f is $2\pi fM$, where

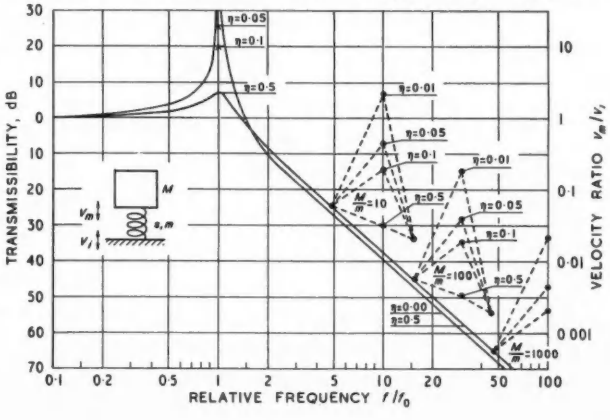

Fig. 2. Curves of transmissibility and corresponding velocity ratios as functions of relative frequency.

f is the vibration frequency [cps]. Also, if s is the stiffness (or spring rate) of the flexible element, m is its mass, and v_m is the vibration velocity of the end of the spring element in contact with M, the velocity ratio v_m/v_i, or its corresponding expression in decibels (i.e., the transmissibility) can be determined from velocity measurements. The theoretical curve for the system in Fig. 1 is shown in Fig. 2, in which the mass M is that of the body to be isolated, and the excitation comes from the lower body, denoted by the subscript i. The curves plotted as solid

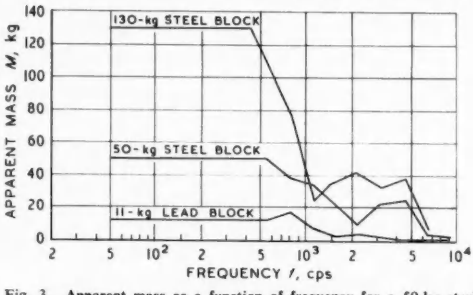

Fig. 3. **Apparent mass as a function of frequency for a 50-kg steel block, a 130-kg steel block, and an 11-kg block.**

lines in Fig. 2 have a resonance peak at $f/f_0 = 1$, where $2\pi f_0 = \sqrt{s/M}$), the height depending on the loss factor or damping ratio η of the flexible element.

In addition, Fig. 2 shows a number of peaks (indicated by broken lines) on the descending flank of the attenuation curves. These secondary resonance peaks are created by the standing waves (of half-wavelength $\lambda/2$) in the flexible element, their frequency depending on the mass ratio M/m and their peak values on the loss factor η. For rubber $\eta = 0{\cdot}1$ and for steel $0{\cdot}01$ approximately. If one such peak occurs at a frequency f_1, it will be followed by lower-amplitude peaks at multiples of this frequency ($2f_1$, $3f_1$, etc.).

Tests on a 400-kg rubber buffer supporting a mass of 130 kg, carried out with the aid of a frequency analyser, clearly showed the existence of these secondary peaks, the main resonance peak being at 35 cps and the secondary peaks at about 1400 and 2800 cps. The corresponding curves for rubber loaded in tension or in shear can also be determined for various applications from the known properties of this material. The behaviour of helical steel springs can also be predicted fairly well up to about 200 cps (above this value the wavelengths become smaller than the distance between two successive coils), and, similarly, fairly good agreement between calculated and measured values can also be obtained for felt and cork loaded in compression.

Summing up, it can be said, although this may seem somewhat paradoxical, that the "softness" of a flexible element is adversely affected in a number of frequency intervals by the mass of the element or, to put it otherwise, at higher frequencies the element becomes stiffer when it is heavier. Consequently, the requirement in most cases is to make the flexible element as light as possible, and the loss factor as high as possible.

Mechanical Impedances

It is remarkable that little has been published on the mechanical impedances Z_f and Z_v of the system represented in Fig. 1, in view of their considerable influence on the effectiveness of the flexible element; this is, however, excusable, because of the very complex variation of the mechanical impedance curves of various structures.

If a massive block of metal, e.g., a steel block of 50 kg, is excited by means of a vibrator with a known force P and a frequency f, then, from the measured acceleration $2\pi fv$ of the block, it is possible to determine the extent to which it can be regarded as vibrating as a single mass, since, for an inert and infinitely rigid mass, $M = P/2\pi fv$, the impedance then being $Z_f = 2\pi fM$. Measurements with a constant value of vibratory force P have shown that the apparent mass M of this 50-kg steel block is 50 kg up to a frequency of about 550 cps; beyond this frequency, the apparent mass of the block decreases linearly to about 12 kg at 2200 cps, rising thereafter to about 25 kg between 3000 and 4500 cps, and finally falling off to about 4 kg at frequencies over 7000 cps, as in Fig. 3. Similar curves are also plotted in Fig. 3 for a 130-kg steel block and for an 11-kg lead block. It is important to note that the apparent mass can easily be ten times lower (or greater) than the actual mass.

In making evaluations it is more convenient, however, to plot curves of impedance as a function of frequency. Both for the internal impedance Z_i and for the foundation impedance Z_f, it is found that, in practical constructions, the values usually obtained are between 10^3 and 10^6 kg/sec. These values are not very different from those of various flexible elements, and, in such cases, it is evident that the resulting improvement, or the difference in velocity levels, will not be as great as those expected, in the first instance, by an evaluation on the basis of Fig. 2.

Laboratory measurements of Z_i, Z_v, and Z_f give, of course, the true values of attenuation and difference in velocity levels. In beams, plates, and bars, the flexural vibrations are reflected at discontinuities (bends or corners, elastic inserts, etc.), and generally an attenuated vibration is transmitted. The ratio of transmitted to reflected energy is a measure of the acoustic decoupling effect of such discontinuities. Fig. 4 shows curves of acoustic decoupling and corresponding velocity ratios as functions of frequency for a plain steel beam, for a

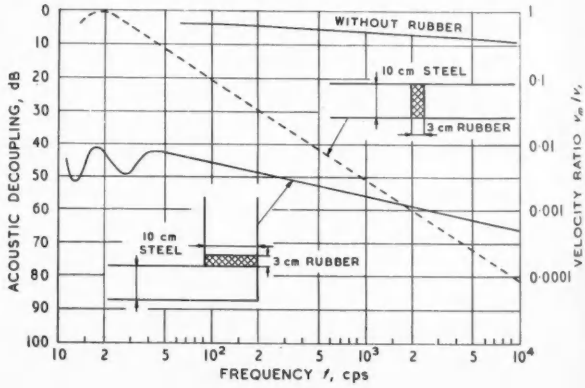

Fig. 4. **Acoustic decoupling and corresponding velocity ratios as functions of frequency for a plain steel beam, for a straight steel beam with a rubber insert, and for angled steel beams with a rubber insert.**

straight steel beam with a rubber insert, and for angled steel beams with a rubber insert.

The agreement between theory and measurement is not very good, because in most cases more than one type of loading (compression, tension, or shear) is involved, and also because the measurement and determination of the complicated vibration phenomena that can occur are very time-consuming. Nevertheless, the order of magnitude of the attenuation can be estimated and can serve to assess the possibilities of improvements to a system.

Fig. 5 shows the comparative results obtained with four different types of flexible elements resting on a steel I-beam and supporting a load of 50 kg in each case. Curve (*a*) for a helical steel spring designed to take a maximum load of 300 kg shows that the spring tends to be less effective at high frequencies. Curve (*b*) refers to a double-U shear type of rubber mounting designed for a maximum load of 80 kg, while curve (*c*) is for the same helical spring as in curve (*a*) but with the addition of rubber cushions, 5 mm in thickness, at either end. Curve (*d*) refers to a balloon-type air cushion designed for a maximum load of 50 kg.

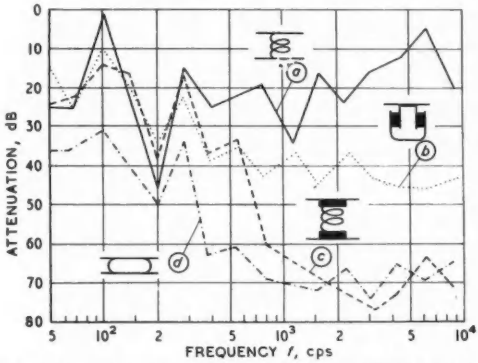

Fig. 5. **Attenuation as a function of frequency for four different types of flexible elements resting on a steel I-beam and supporting a load of 50 kg.**

Conclusion

In general, it may be said that structure-borne noise is transmitted mainly by flexural vibrations but, owing to the complexity of structures, torsional or other types of vibrations can also occur, complicating the motion and often reducing the attenuation to less than its expected value. The use of rubber pads on steel springs enables fixing couples to be avoided by a soft shearing or bending movement. In such composite arrangements, rubber, cork, or felt give good results, provided that the pad thickness is sufficient. This also applies when the mountings consist solely of layers of these materials. The main principle to be observed in noise reduction is therefore, not primarily the introduction of damping (which can be a disadvantage at high frequencies), but the application of acoustic decoupling, which gives " freedom " to the noise source, so that it can expend itself in a low-impedance element.

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U.S.A.

The Heat Treatment of Sintered-Iron Parts

By I. LJUNGBERG and P. ULF GUMMESON. (From *Precision Metal Molding*, Vol. 17, No. 4, April 1959, pp. 30, 31, 58, 7 illustrations)

THE wear characteristics of sintered parts which have been case-hardened and heat-treated are generally very good, but a high sintered density and a favourable chemical composition are essential.

Although it is not always true, it is often difficult to obtain reproducible hardness tests on sintered parts, in which the density is a very important factor. In this connection, a number of tests have shown that the Brinell hardness test is the most reliable, though it is a fairly slow method. Hardness has also been measured by the Rockwell 15 T method, in which the impression is made by a steel ball of $\frac{1}{16}$ in. diameter, using a preload of 3 kg and a second load of 12 kg. This test takes very little time, and the results with it show that there is a continuous correlation between hardness and density, hardness increasing with increasing density, assuming that the thickness of the carburized layer remains constant. It therefore appears that in many cases hardness can be used to determine the density of a sintered part.

For testing the hardness of hardened sintered parts, it is better to use the Rockwell 30 N method, in which a 120-deg. diamond cone is used, the load in this case being 30 kg. In this connection, it should be understood that the core of a sintered plain-iron part will not be changed in hardness during case-hardening, but that the surface of the part will be much harder as a result of carburization. If such a part is hardness-tested by the Rockwell C method with a load of 150 kg, the diamond cone will penetrate into the soft core and will give hardness values which are too low. Actually, this can also happen with the Rockwell 30 N method if the carburized surface layer is very thin.

A series of hardness tests has been made in Sweden by Husqvarna Vapenfabriks A/B on sintered-iron specimens of different densities, measuring $10 \times 20 \times 25$ mm, carburizing being effected for different periods in a cyanide bath. The results, using the Rockwell 30 N method, were somewhat unexpected, it being found that hardness increases with increased time in the cyanide bath. Furthermore, hardness was found to be a maximum for a density somewhere between 6·0 and 6·5 gm/cm³, and a minimum for a density of about 6·9 gm/cm³, after which hardness increased with increasing density. The explanation lies in the fact that hardness is dependent on carburization depth, which is itself dependent on density.

Tests were also carried out to determine hardness as a function of density after 80-min case-hardening at 850°C, the testpieces being carburized throughout at densities between 5·4 and 6·4 gm/cm³. It was found that, at these densities, hardness increases linearly with increasing density, with a rapid change in hardness from the maximum at 6·4 gm/cm³ to a minimum at 6·9 gm/cm³,

obviously caused by the rapid change in carburization depth at these densities. At densities higher than 6·9 gm/cm³, carburization is constant, and a regular increase in hardness therefore takes place. These differences are levelled off with heavier carburization or longer times.

It might be assumed that there should be an almost linear correlation between density and carburization under favourable conditions. Metallographic examination shows, however, that the density of the surface layer is of extreme importance. Thus, it was noted in one case that the carburization of the two surfaces meeting the punches was lower than on other surfaces. To study this problem, a separate investigation was made, in which carburization was measured after the testpieces had been subjected to different surface treatments before case-hardening, i.e., slight grinding or the removal of 0·5 mm by grinding. The results of this investigation tend to indicate that carburization decreases with increased surface grinding, but there is unfortunately much left to be explained in connection with this subject and further investigations are necessary.

In addition, some investigations were made with regard to pack-carburizing at 910°C, the testpieces being packed in steel containers with solid carburizers. The time for carburizing was counted from the moment the boxes reached the furnace temperature (in about 20 min), and cooling was effected in the boxes, after which the testpieces were heated to 850°C in a cyanide bath and then quenched in oil. The results were similar to those for cyanide hardening, but the deeper carburization noted caused the hardness minima to be less noticeable. Fig. 1 shows Rockwell 30 N hardness as a function of carburization depth for a density of 7·0 gm/cm³, and compares the results obtained for cyanide hardening at 850°C, followed by quenching in oil (curve (1)), and for carburization in a solid carburizer at 910°C, followed by cyanide hardening at 850°C and quenching in oil (curve (2)).

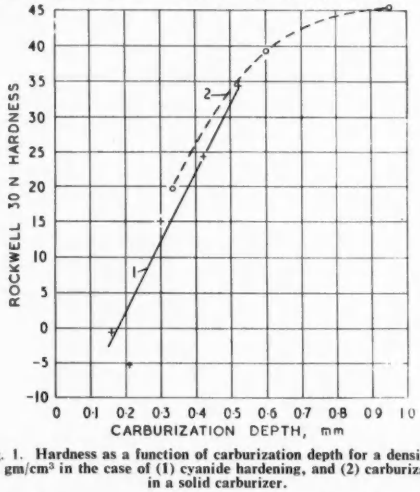


Fig. 1. Hardness as a function of carburization depth for a density of 7·0 gm/cm³ in the case of (1) cyanide hardening, and (2) carburization in a solid carburizer.

With regard to the influence of alloying elements, it should be noted that really high hardness values are difficult to obtain during the case-hardening of sintered parts made from unalloyed iron powders. There are various methods of adding such alloying elements as manganese, chromium, nickel, molybdenum, and copper for the purpose of decreasing quenching speed and at the same time for increasing the depth of carburization. The main problem, however, is to obtain a homogeneous material, because of the low diffusion rate of these alloying constituents in iron. It would appear that the material with the best qualities in this respect is copper, and some comparative results with unalloyed iron powder and iron powder containing 2% copper are shown in Table I.

TABLE I: STRENGTH OF UNALLOYED AND ALLOYED ELECTROLYTIC IRON POWDER

Type of Material	Density [gm/cm³]	Carburization Depth [mm]	Hardness [R 30 N]	Impact Strength [kg/mm²]	Transverse Rupture Strength [kg/mm²]
Unalloyed	7·00	0·27	45	440	63
Unalloyed	7·00	0·35	48	416	65
Unalloyed	7·00	0·70	55	395	84
Unalloyed	7·48	0·35	43	632	93
Unalloyed	7·48	0·50	54	563	97
Unalloyed	7·48	0·80	59	465	110
2% Cu alloy	7·28	0·40	65	427	81
2% Cu alloy	7·28	0·60	70	380	87
2% Cu alloy	7·28	0·90	70	350	97

Mention should also be made of the question of uneven density. In this connection, it is impossible, when carburizing a sintered part, to adjust the process for the differences in density within one part. A part with low and uneven density will be carburized unevenly, causing uneven hardness and varying impact strength. It is for this reason that tools for the pressing of parts intended to be carburized should be designed to give as uniform a density as possible.

For the selection of sintered parts to be hardened, the general rules regarding quality and heat treatment can be summarized as follows:—

When parts weighing less than 30 grams and with a thickness of less than about 6 mm are made, good results may be obtained with unalloyed powder. A cyanide-bath hardening for about 30 min confers hardness values which can be measured. For larger parts, it seems economical to carburize in solid carburizers, particularly if high hardness is desirable. This pack-carburizing should be carried out at 910°C.

When the carburized layer is more than 1 mm thick, hardness increases very little, and the use of copper additions is recommended. Copper additions are not, however, recommended in the case of parts with fairly thin sections required to have high impact strength. Cyanide-bath hardening should generally be effected at 850°C. Higher temperatures will give more rapid carburization but will also increase the danger of giving rise to changes in the shape of the part.

If parts are to be pack-carburized, heat treatment must be carried out in a salt bath between 825 and 850°C, a slightly carburizing salt bath being preferable, because the so-called neutral salt bath is generally somewhat decarburizing. Annealing in muffle furnaces is not recommended, as the parts will be oxidized easily. The drawback to annealing in a salt bath is trapping of the salts in the pores, and these salts may eventually sweat out, particularly in the case of parts of comparatively low density. Careful washing of the parts in water may solve this problem.

One of the greatest difficulties in connection with the hardening of sintered parts is the control of dimensional changes. Both growth and shrinkage may to some extent be controlled by the depth of carburization, but it has sometimes proved economical to control dimensions by grinding after hardening when tolerances are narrow.

Radioactive Methods of Determining the Influence of Viscosity on Lubricant Film Thickness

By D. PAVELESCU and I. ILIUC. (From *Revue de Mécanique Appliquée*, Vol. 3, No. 3, 1958, pp. 299–312, 8 illustrations)

ALTHOUGH the mechanism of lubrication has been actively investigated, there appears to be considerable differences of opinion regarding the influence of film thickness on hydrodynamic lubrication. Thus, for example, some investigators have stated that, for ensuring hydrodynamic lubrication, film thickness can vary between 100 and 6000 Å. Furthermore, although modern theories on intermolecular and surface actions have undoubtedly contributed to a better theoretical understanding of the subject, uncertainties still remain, inasmuch as it has been possible to confirm theoretical conditions in a few isolated cases only.

Of the principal factors affecting lubrication, only the part played by two factors, i.e., viscosity and lubricant film thickness, have been considered in this paper, use being made of two measuring methods utilizing radioactive tracers and a Geiger-Müller counter. For this purpose, two circular metallic plates of radius R with lapped surfaces are employed, and between these plates a viscous flow is created, exclusively produced by external forces at right angles to the surfaces of the plates.

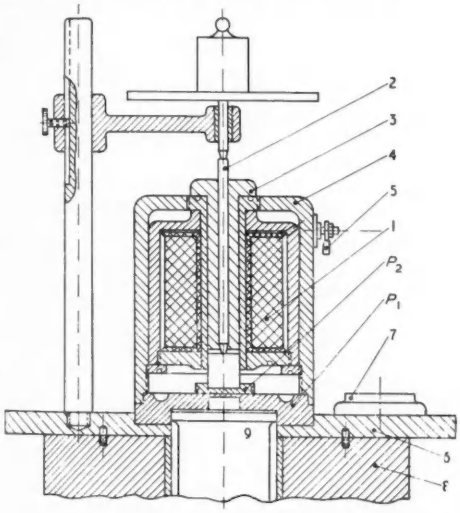


Fig. 1. **Equipment for investigating variations of film thickness δ by method I.**
(1) Electromagnet. (2) Load transmission rod. (3) Soft-iron core. (4) Aluminium jacket. (5) Terminal of electromagnet. (6) Baseplate. (7) Spirit-level. (8) Lead wall. (9) Geiger counter. P_1, P_2 Aluminium plates.

Theoretically, film thickness δ can be expressed by the following simplified equation, which is valid up to values of δ of 2·5 μ:—

$$\delta = \tfrac{1}{2}R\sqrt{3\eta/\sigma t} = \tfrac{1}{2}R\sqrt{3\eta/\eta_z} \quad .. \quad .. \quad .. \quad (1)$$

where η is the dynamic viscosity, σ is the specific stress or loading, t is the rupture time, and η_z is the rupture viscosity ($= \sigma t$). It will therefore be noted that, if other factors remain constant, the minimum film thickness δ_0 for hydrodynamic flow to be maintained is a function of the plate area, the dynamic viscosity, the specific loading, and the rupture time.

The simple experimental equipment used was devised to meet the conditions required for checking the relations in eq. (1) and for effecting measurements of film thickness, determinations being made by means of two different methods. Basically, the first method consists of compressing the radioactive lubricant and simultaneously measuring the specific radioactivity. The determination of successive film thicknesses, corresponding to various values of σt, is then effected by comparing the counting rates obtained with the Geiger counter with those for a reference plate measured under similar conditions.

The equipment used for method I is shown in Fig. 1. Between the aluminium plates P_1 and P_2 viscous flow is obtained by means of a known external load, axially applied by the load transmission rod (2). The plate P_1 acts as a diaphragm in front of the mica window of the Geiger counter (9). The diaphragm is of sufficient thickness to be able to absorb fully the β-radiation of 1·7 MeV of the radioactive phosphorus used as a tracer, with the exception of those radiations originating from a central region of 12 mm diameter, where the thickness of the aluminium diaphragm is only 0·6 mm. It should be noted that plate P_1 is also used as a reference supporting plate, measurements in this case also being effected in the presence of plate P_2. Determinations are interrupted when, under the specific loading σ and as a result of the increase in time t, the counting rate obtained with the Geiger counter remains constant.

This equipment has the advantage of permitting repeated measurements to be made under exactly similar conditions of geometry, oil quantity, etc. by external means, i.e., load removal by operation of the electromagnet (1), without interfering with the internal arrangements of the equipment.

Method II also consists of obtaining the same viscous flow phenomenon under a specific load σ; in this case, however, the excess lubricant due to compression is removed from the lower plate after each interval $\Delta t = t_2 - t_1$, after which the two plates are separated by the electromagnet. The supplementary equipment used for Method II is shown in Fig. 2, and basically comprises the use of a steel basin (10) and an electrical resistance heater (11), enabling measurements to be taken at various temperatures. In this case, plates P_1 and P_2 are made of tempered steel, and the film thickness after each determination is measured by comparing the radioactivity of the lubricant left on the plates with an identical reference supporting plate, measured with the Geiger counter under similar conditions but without the intermediate

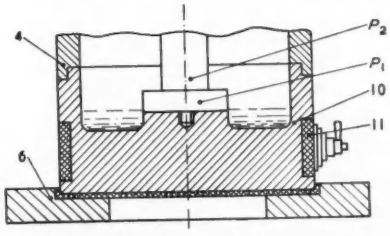


Fig. 2. **Supplementary equipment for method II.**
(4), (6) Aluminium jacket and baseplate, as in Fig. 1. (10) Steel basin. (11) Resistance heater. P_1, P_2 Steel plates.

diaphragm P_1 in Fig. 1. In practice, as tests showed equal distribution of lubricant on both the plates P_1 and P_2 in Fig. 2, it is sufficient to record the counting rate obtained with the lower surface of plate P_2.

With both methods, which assume relative determinations on the basis of a reference with respect to thin films of lubricant (0·5 to 15μ) and the use of radioactive phosphorus with its high-energy β-radiation, the volume of oil V_s on the experimental plate is obtained from the relation

$$V_s = V_e I_s / I_e \qquad (2)$$

where V_e is the volume of the reference oil film and I_e and I_s are the respective counting rates.

Tests were carried out on a number of irradiated lubricants of different viscosities, including mineral oils, paraffin oil, and castor oil. In addition, tests were effected on paraffin oil with an oiliness additive, oleic acid being used for this purpose.

Irradiation was obtained in two ways, i.e., (1) by dissolving in the lubricant radioactive phosphorus P^{32} obtained under a flux of 10^3 neutrons per cm^2 per second, or (2) by irradiation of one of the mineral oils containing 0·1% sulphur, among other impurities, under a flux of 10^{12} neutrons per cm^2 per second.

In general, the specific radioactivity of the lubricants used was 250 microcuries/cm^3, this value being so chosen as to ensure oil-films with values of minimum thickness δ_0 having activities of more than fifteen times the background value (24 to 30 pulses per minute). In addition, loads were kept as small as possible, so as to have reduced values of specific loading σ, thereby maintaining conditions where the influence of variations in viscosity as a result of variations in pressure could be neglected.

Comparison of the Experimental Methods Used

Fig. 3 shows comparative results of film thickness δ as a function of rupture viscosity $\eta_z = \sigma t$ with method I (curve (1)) and method II (curve (2)), curve (3) giving the theoretical result in accordance with eq. (1). In these tests, the plates P_1 and P_2 were 20 mm in diameter, the specific loading σ being 1·5 kg/cm^2. The test temperature

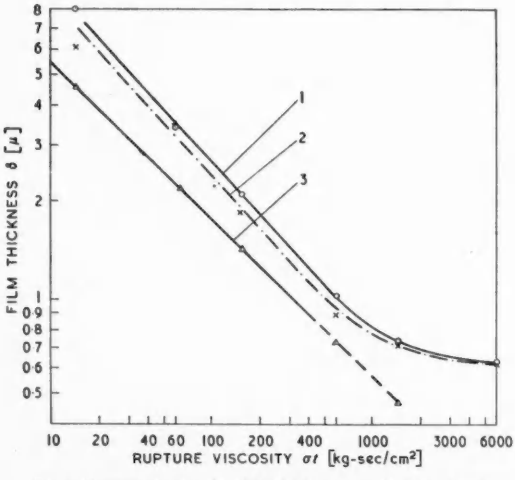


Fig. 3. Comparison of results of film thickness δ as a function of rupture viscosity σt obtained from (1) method I, (2) method II, and (3) theoretically from eq. (1).

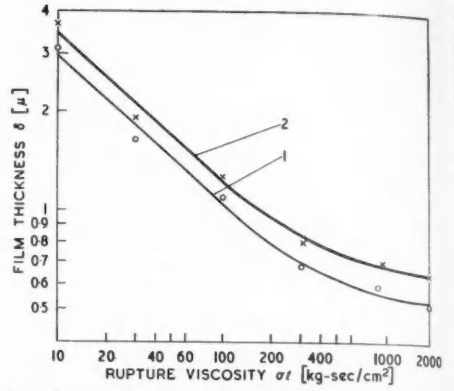


Fig. 4. Influence of oiliness additive, showing curves of film thickness δ as a function of rupture viscosity σt for (1) paraffin oil, and (2) paraffin oil containing 5% oleic acid.

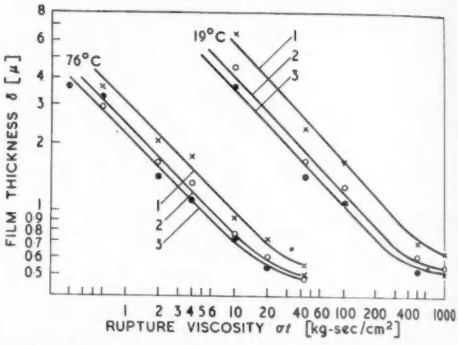


Fig. 5. Influence of temperature and viscosity, showing curves of film thickness δ as a function of rupture viscosity σt for three oils of different viscosity at 19°C and 76°C.

was 21°C, at which the viscosity η of the mineral oil used (the irradiated oil containing sulphur) was 4·05 poises.

These results indicate that method I is better than method II, as (quite apart from its comparative simplicity and easy reproducibility) it gives rise to smaller relative errors, with considerably less scatter. It will, however, be noted, that the slope of the curves obtained with both methods resembles that of the theoretical curve, but that, in the region of low values of δ, the values obtained from eq. (1) cause the curve to be displaced below the experimental curves. This is due to the fact that eq. (1) does not take into consideration such factors as the type of metal used, surface roughness, chemical composition, and temperature. It is therefore necessary to complete the expression by a correction coefficient K (greater than unity) which, however, can easily be determined experimentally as a function of these factors.

Influence of the Oiliness Additive

As already mentioned, oleic acid was selected as the oiliness additive and paraffin oil as the basic lubricant, as the latter has considerably less viscosity than the irradiated mineral oil used in the comparative tests detailed above. Fig. 4 shows the curves of film thickness δ as a function of rupture viscosity $\eta_z = \sigma t$ for paraffin oil at a temperature of 21°C with $\eta = 2{\cdot}23$ poises (curve (1)), and for paraffin oil with 5% oleic acid (curve (2)).

In these tests, method II was employed, using tempered

steel plates of 12 mm diameter and a specific loading σ of 0·4 kg/cm². Incidentally, it should be noted that, in all cases where steel plates were used, the chemical reaction noted between the radioactive tracer and the metal was much stronger than it was in the case of aluminium plates.

Influence of Temperature and Viscosity on Film Thickness

For the purpose of determining the influence of temperature and viscosity on film thickness, tests were carried out on three oils of different viscosity, i.e., the irradiated mineral oil containing sulphur, already mentioned, another mineral oil of lower viscosity containing radioactive phosphorus, and castor oil containing radioactive phosphorus, of comparatively low viscosity. The tests were conducted at temperatures of 19°C and 76°C by means of method II, using tempered steel plates of 12 mm diameter and specific loadings σ of 0·4 and 0·04 kg/cm². The results obtained are shown in Fig. 5.

It would appear that, at the higher temperature, rupture viscosity σt and the temperature itself are decisive factors influencing film thickness, the viscosity of the lubricant playing a comparatively small part. In fact, a general conclusion to be drawn is that viscosity exercises a direct influence on lubricant film thickness only when the other factors remain constant, this influence decreasing in the range of thin films.

Conclusions

Examination of Figs. 3, 4, and 5 indicates the existence of a zone between about 1 and 6 μ where film thickness δ seems to be linearly proportional to rupture viscosity $\eta_z = \sigma t$. The most interesting zone, however, is for values of δ less than 1 μ, and it will be noted that flow ceases to be hydrodynamic below values of about 0·8 μ, irrespective of other factors, such as temperature, viscosity, oiliness, load, chemical composition, area, surface roughness, etc. It should also be mentioned that there is, in fact, another zone (between 6 and 15 μ) where surface roughness does not have any marked influence. However, tests were not conducted in this zone, as they lead to small values of σt, i.e., to extremely small values of specific loading σ or of time t, both of which are difficult to reproduce in practice, owing to the large errors involved.

This investigation has succeeded in indicating two convenient and fairly accurate methods of measurement, permitting further research in this field to be continued, the relative errors resulting from their use (± 1 to $\pm 7\%$) being quite incapable of influencing qualitatively any conclusions drawn for film thicknesses below 8 μ. Furthermore, these radioactive methods permit easy investigation of the zone below 1 μ, though admittedly they necessitate the use of superfinished surfaces, with roughnesses between 0·025 and 0·050 μ.

RUSSIA

Investigations into Techniques for Producing Cast Silicon Components

By A. M. Suvorov. (From *Liteinoye Proizvodstvo*, No. 3, March 1959, pp. 14–16, 3 illustrations)

As the corrosion resistance of alloy steels sharply decreases at temperatures above 100 to 150°C, considerable interest has been aroused in Russia regarding the use of crystalline silicon, which is characterized by excellent corrosion resistance, even at temperatures as high as 500 to 600°C. However, crystalline silicon has a number of unfavourable properties which have hindered its use as a material for cast components. Thus, it has high hardness and brittleness, excluding it from being worked by conventional machining methods. Furthermore, it is liable to cracking under the action of thermal and residual stresses and becomes rapidly contaminated by non-metallic inclusions while in the molten state. All these properties tend to complicate the production of cast silicon components.

To overcome these difficulties, a series of investigations has been carried out in Russia, these being divided into two main parts, i.e., (1) the metallurgical cycle, which includes the melting process, and (2) the technological cycle, which includes the preparation of moulds, casting techniques, and the cooling and machining of the cast components. Special attention was paid to the problem of interaction between silicon and the furnace lining, to the melting atmosphere used, to the selection of mould materials, and to establishing optimum heat zones for casting and cooling. In addition, methods of mechanical working, microstructure, and the mechanical properties of cast silicon were studied.

To satisfy the requirement for high corrosion resistance in contact with hot acids, silicon of at least 98 to 99% purity was used. The melting process was carried out in a high-frequency induction furnace in a vacuum, in air, in various protective atmospheres, and under a shield of fluxes. A decisive factor in the selection of furnace linings was the fact that silicon has such a high electrical resistance at a temperature of less than 1000°C that it does not melt under the influence of induction heating, while above 1000°C its electrical resistance decreases sharply and melting is effected both by induction and by heat transfer from the furnace walls.

The furnaces used were made of graphite or of graphite combined with a refractory, i.e., fused quartz glass or aluminium oxide, but minimum contamination of silicon by carbides and oxides was obtained with a combination of high-density graphite and fused quartz glass. These materials were dried before melting at 150 to 200°C for 48 hr and were then baked at 800°C for 4 hr. During the melting operation, the furnace was preheated to from 800 to 1000°C, and the crushed silicon, in pieces of about 10 to 15 mm in diameter, was charged into the furnace. Pouring of the molten silicon into the moulds was carried out at 1550 to 1600°C. All these temperatures were measured by optical pyrometers.

During trial meltings in various environments it was found that, in air, oxidation of the silicon starts at 1000°C and increases sharply at higher temperatures. The resulting silicon dioxide cannot easily be separated from the melt and will later be the cause of non-metallic inclusions in the castings. During preheating of the melt in air, silicon monoxide is also formed and cannot be separated at all from the melt, giving rise to porosity, gaseous inclusions, and cavities, particularly at feeder heads and heavy

sections in the cast components. Gas absorption in the silicon may to some extent be decreased by shortening the melting period, by accurate preheating of the furnace, and by careful heat treatment of the furnace linings immediately before melting. Another cause of impurities is carbon monoxide, which appears in the free state and which can cause the formation of carbides in the melt, decreasing the corrosion resistance of silicon. The source of the carbon monoxide contamination is the graphite lining of the furnace walls.

For providing a protective atmosphere during melting, argon and nitrogen were used. It was found that argon decreased gas absorption and oxidation of the melt, while nitrogen exercised a harmful effect on the melting process, since it led to the formation of nitrides at temperatures of 1300 to 1450°C.

The protective fluxes used were based on calcium fluoride and were found to decrease the contamination of silicon by oxides to a great extent. For de-oxidation, good results were also obtained by adding 0·5% aluminium to the melt just before pouring.

Casting techniques were studied in connection with the production of various items, including cylindrical containers with a wall thickness of 2 to 3 mm and from 30 to 80 mm in diameter and from 50 to 60 mm in height, and tubes with a wall thickness of 3 to 6 mm and from 30 to 64 mm in diameter and from 80 to 400 mm in length.

The moulds used were made of a great variety of materials, including sand, gypsum, ceramics, asbestos, and graphite. Sand moulds were dried at a temperature of 120°C for 2 hr and baked at temperatures which were gradually increased to from 700 to 850°C. It was found that sand moulds were unsuitable for casting silicon, since cracks were observed in all finished components. Similarly, negative results were recorded with moulds made of asbestos, gypsum, chamotte, and silver graphite, as, owing to the heavy interaction between silicon and these materials, good-quality castings could not be obtained.

Another type of mould, using mixtures of various sands with bakelite powder, zirconium sand, and graphite, was also used. With these moulds, which were preheated to 400°C, the castings produced had much smoother surfaces but did not have sufficient accuracy.

Considerably better results were obtained with special ceramic moulds, the base material of which was ethyl silicate and sodium silicate, with additions of talc and silver graphite to improve plasticity, and of quartz, zirconium oxide, and titanium oxide to produce smoother surfaces. Altogether, twenty-two different mixtures were tested to find the best composition for these ceramic mould materials and for the corresponding facing materials, the tests being carried out with moulds of various shapes, including 6- and 8-sided moulds, on each face of which a different facing material was applied.

The ceramic moulds were preheated before casting to from 800 to 1050°C, and the suitability of various mixtures was established after careful examination of such factors as the degree of intermixing between mould material and silicon and the presence of cracks, cleavages, gaseous inclusions, and shrinkage defects in the castings. Mixtures containing ethyl silicate were found more resistant to silicon than mixtures containing sodium silicate. On the other hand, the ethyl silicate mixtures did not prove satisfactory for casting tubes, owing to the production of cracks. Preheating above 1200°C did not prevent these defects and, in addition, led to the formation of flash on the cast surfaces. Another drawback of ceramic moulds is that their use is limited to smaller components.

Good-quality castings were also produced from high-density graphite moulds. A salient factor of high-density graphite is that it does not intermix with silicon and makes it possible to obtain smooth surfaces. Low-density graphite, however, leads to the formation of surface defects, owing to its porosity.

In the design of a suitable moulding assembly, two main requirements were taken in account, i.e., the mould must be easily assembled, and the finished castings must be capable of easy extraction. The application of special vertical moulds for casting components such as tubes and deep tubular containers made it necessary to select materials carefully and to pay special attention to the design of the mould assembly. Thus, materials had to possess good refractoriness, sufficient chemical stability, and adequate strength at the casting temperatures employed, while the finished components had to be easily separable from the moulds. For shaping the components internally, several types of tubular cores were tested, including graphite tubes made up of three sections, graphite tubes with a taper of 2 deg., thin-walled graphite tubes (1·5 mm wall thickness), and aluminium-alloy tubes. The best results were obtained with the thin-walled graphite tubular cores and hence these were incorporated into the final assembly.

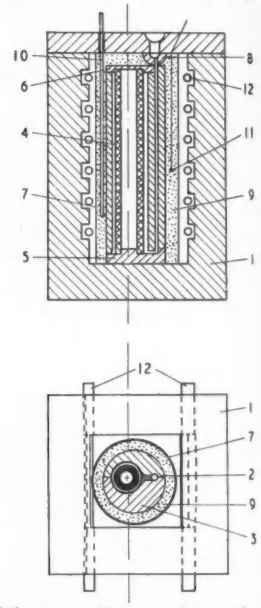


Fig. 1. Arrangement of experimental moulding assembly for casting silicon tubes.

Fig. 1 shows a moulding assembly used for casting tubes. In this arrangement, the mould is made up of two parts (2) and (3), which are held together by means of a baseplate (5) and a cover (6), recesses being incorporated in the cover for the accommodation of a casting gate (8) and a thin-walled graphite tubular core (4). The assembled mould is placed in a steel cylinder (7), the space between the outside mould walls and the cylinder being filled with graphite powder (9). The cylinder (7) is placed in an electric resistance furnace (1) fitted with Silit heating elements (12) in two sections, each of which has a capacity of 3 kW and can reach a maximum heating temperature of 1250°C. Before casting, the mould is preheated to from 800 to 1000°C and is then allowed to cool in the fur-

nace, temperatures being measured by a thermocouple (11). In order to prevent burning out of the graphite powder during heating, nitrogen is introduced between the moulds and the cylinder (7) through a porcelain tube (10).

It was found that, when the recommended thermal zone was exceeded, the castings tended to crack under the action of thermal and shrinkage stresses. When the mould was preheated to 1200°C, sandy scale invariably appeared on the surface of the components. On the other hand, observance of the recommended thermal limits helped to avoid uneven drops in temperature and ensured uniform solidification of the castings.

Owing to their great hardness and brittleness, the mechanical working of cast silicon components by conventional metal-cutting processes is impossible, while machining with abrasive wheels is extremely unproductive and inefficient. Ultrasonic machining appeared to be the only feasible method and, to investigate this possibility, use was made of a laboratory ultrasonic machine with an output of 4·8 kVA at a frequency of 20 kcps, or 4·3 kVA at 25 kcps, the rate of metal removal varying between 40 and 150 mm³/min. During these tests it was found that the most effective frequencies were 18 kcps for cutting,

(*Concluded on page 256*)

JAPAN

The Effect of Shot-Peening on the Fatigue Strength of Metals

By S. Takeuchi and T. Homma. (From *The Science Reports of the Research Institutes, Tôhoku University*, Series A, Vol. 10, No. 6, pp. 426–434, and Vol. 11, No. 1, pp. 48–55, 13 illustrations.)

In general, metals and alloys under repeated loading are subject to fatigue, finally rupturing at a stress which is below the tensile or yield strength. When repeated stress is imposed on the material, a number of structural imperfections or minute cracks in the surface layer gradually propagate inwards, resulting in fatigue failure. Furthermore, if oxidation or decarburization occurs in the surface layer, its strength decreases, while the presence of notches causes stress concentrations, in both cases leading to early failure of the material. Consequently, to enhance fatigue strength, it is desirable to harden the surface layer and to eliminate the presence of notches.

Methods of hardening the surface layer include carburizing, nitriding, induction heating and quenching, surface-rolling, and shot-peening. Of these, the first three methods are applicable to iron and steel but hardly to other alloys, while surface-rolling gives rise to a number of practical difficulties. Consequently, as shot-peening is comparatively simple and has proved effective, the present investigation is concerned with fatigue tests carried out on polished and shot-peened specimens of pure iron, a brass, a Si-Mn spring steel, and an aluminium alloy, the chemical compositions of which are given in Table I. Also, as iron and steel products generally have a decarburized layer, it was considered desirable to carry out additional tests to clarify the effects of shot-peening on the Si-Mn spring steel with a decarburized layer, as it was believed reasonable to expect that shot-peening should have a beneficial effect on fatigue strength in such a case.

Table I: Percentage Composition of Specimens Tested

	Iron	Brass	Si-Mn Steel	Al-Alloy
Carbon	0·053	—	0·540	—
Silicon	0·160	—	1·500	0·50
Manganese	0·110	—	0·810	0·54
Copper	—	59·22	0·230	4·06
Chromium	—	—	0·034	—
Zinc	—	39·93	—	0·45
Iron	99·667	0·15	96·866	0·49
Lead	—	0·29	—	—
Tin	—	0·41	—	—
Magnesium	—	—	—	0·83
Phosphorus	0·004	—	0·007	—
Sulphur	0·006	—	0·013	—
Aluminium	—	—	—	93·13

Before use, all specimens were subjected to heat treatment, i.e., 980°C for the iron, 650°C for the brass, 850°C for the Si-Mn steel, and 415°C for the aluminium alloy. In all cases, the duration of heat treatment was 1 hour, and the specimens were allowed to cool in the furnace.

Effects of Shot-Peening on Polished Specimens

After polishing with fine emery paper, the specimens were shot-peened with a machine of the air-nozzle type, using No. 24 chilled cast-iron shot and an air pressure of from 5 to 6 kg/cm². Fatigue testing was carried out on a rotary bending machine operating at 2000 rpm, a rupture strength at 10^7 cycles of repeated loading being taken as the fatigue limit. These fatigue tests were effected on three types of specimen, i.e., (1) a specimen polished with fine emery paper, as a reference standard, (2) a specimen shot-peened after polishing, and (3) a specimen polished, shot-peened, and then re-polished after peening to leave only the hardened layer. The thickness of the layer removed by this re-polishing after shot-peening was 0·05 mm in the case of iron, 0·1 mm in the case of the brass and the aluminium alloy, and 0·04 mm in the case of the Si-Mn steel.

The results of these fatigue tests showed that there were no conspicuous differences between the shapes of the *S-N* curves for polished specimens and shot-peened specimens, but it was clear that all the shot-peened specimens had fatigue strengths several times greater than those of specimens which had merely been polished. Furthermore, the shot-peened specimens had rupture strengths at 10^7 cycles which were appreciably higher than those of the polished specimens without shot-peening. Thus, in the case of the brass, for example, the polished specimen fractured under a stress of 21·4 kg/mm² at 4×10^5 cycles, while the shot-peened specimen fractured at about 16×10^6 cycles. The fatigue limit at 10^7 cycles of the polished brass specimen was 18·0 kg/mm², compared with 20·4 kg/mm² for the shot-peened specimen, representing an increase of about 13%. In the case of the specimens which had been re-polished after shot-peening, both the life and the fatigue limit were high in comparison with specimens which had merely been polished, but were substantially the same or only very slightly higher than those noted for shot-peened specimens without re-polishing. A summary of the experimental results obtained is given in Table II.

It should be noted that, although shot-peening hardens

TABLE II: SUMMARY OF EXPERIMENTAL RESULTS

Specimen	Tensile Strength [kg/mm²]	Increase in Hardness by Shot-Peening [%]	Increase in Fatigue Limit by Shot-Peening [%]
Iron	30·4	56	3
Brass	43·3	88	13
Si-Mn Steel	87·6	43	5
Al-Alloy	24·5	40	11

the surface layer, with a beneficial effect on fatigue strength, it also tends to produce uneven surfaces as a result of the impact of the shot, thus producing notches or sites of stress concentration, which have an adverse effect on fatigue strength. If, therefore, a specimen is annealed at high temperatures after shot-peening, the hardened layer will naturally be softened, leaving only the uneven surface, enhancing the notch effect and causing the fatigue strength to drop considerably. This is confirmed by the results shown in Fig. 1, which refers to tests carried out on specimens of the Si-Mn spring steel which

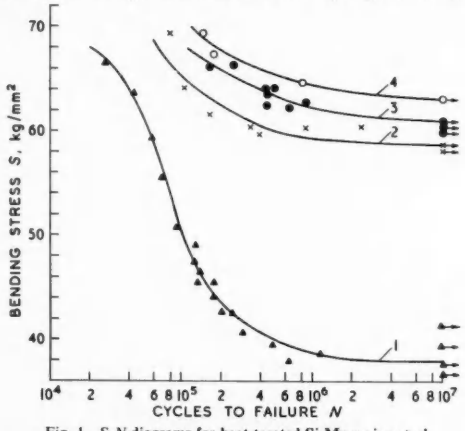


Fig. 1. *S-N* diagrams for heat-treated Si-Mn spring steel.
(1) Polished, shot-peened, and annealed specimen.
(2) Polished specimen.
(3) Polished and shot-peened specimen.
(4) Polished, shot-peened, and re-polished specimen.

were initially oil-quenched at 850°C and tempered for 1 hr at 520°C. Thus, curve (2) shows the results for a polished specimen, curve (3) for a polished and shot-peened specimen, and curve (4) for a polished, shot-peened, and re-polished specimen, while curve (1) shows the pronounced drop in fatigue strength obtained with a specimen which, after polishing and shot-peening, was further annealed at 500°C for 1 hr in a vacuum.

EFFECTS OF SHOT-PEENING ON DECARBURIZED STEELS

In this investigation, two types of fatigue test, i.e., rotary-bending at 2000 rpm, and reversed torsion at 3000 rpm, were carried out on the Si-Mn spring steel, the specimens being subjected to a heat treatment comprising heating to 850°C for 1 hr and allowing to cool in the furnace, followed by heating to 850°C for 30 min and oil-quenching and subsequent tempering at 520°C for 1 hr and cooling in air.

Four different types of specimens were used for these tests, i.e., (1) a polished specimen, as a reference standard for decarburized specimens, (2) a polished and shot-peened specimen, (3) a decarburized specimen, and (4) a decarburized specimen subjected to shot-peening. The corresponding *S-N* diagrams for rotary bending tests are shown in Fig. 2, in which it will be seen that the fatigue limit of the polished specimen (curve (2)) was about 59 kg/mm² at 10^7 cycles, as compared with 61 kg/mm² for the polished and shot-peened specimen (curve (1)), representing an increase of only 3% as a result of shot-peening. The fatigue limit at 10^7 cycles of the decarburized specimen (curve (4)) was only 31 kg/mm², whereas the corresponding value for the shot-peened decarburized specimen (curve (3)) was 48 kg/mm², representing an increase of as much as 54%.

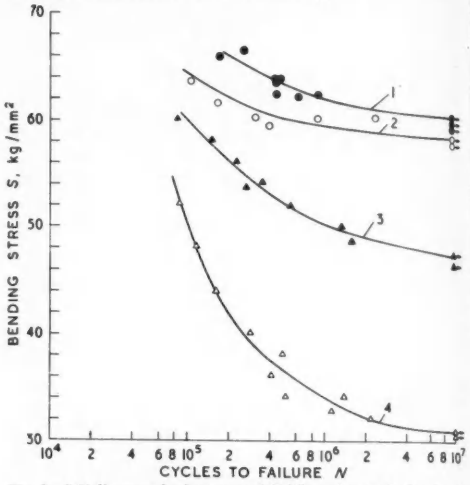


Fig. 2. *S-N* diagrams for heat-treated Si-Mn spring steel, showing the effect of decarburized layers.
(1) Polished and shot-peened specimen.
(2) Polished specimen.
(3) Specimen with shot-peened decarburized layer.
(4) Specimen with decarburized layer.

Similar results were obtained in the case of reversed-torsion tests. Thus, in these tests, the fatigue limit at 10^7 cycles of the polished specimen was found to be about 41 kg/mm², as compared with 42·5 kg/mm² for the polished and shot-peened specimen, i.e., again an increase of 3%. The fatigue limit of the decarburized specimen was 23 kg/mm², while that of the shot-peened decarburized specimen was 33 kg/mm², representing a substantial increase of about 43%.

In addition, a number of tests were carried out to determine the influence of the thickness of the decarburized layer on fatigue strength. It is considered that, unless further tests are carried out, no definite quantitative conclusions can be drawn regarding the relation between the thickness of this layer and the decrease in fatigue strength. It would appear, however, that the critical thickness, responsible for reducing the fatigue strength of a specimen by about 50%, is less than 0·05 mm and that any further increase in thickness does not cause any appreciable difference.

Finally, tests were carried out to ascertain the effect of shot-peening intensity on the fatigue strength of decarburized specimens. Here again, it is difficult to draw definite conclusions, but it would appear that increased intensity of shot-peening has a beneficial influence on the fatigue strength of decarburized specimens, even to the point of causing it to rise to approximately the same value as that of polished specimens.

Improved Hot-Gas Engine, using a Rhombic Drive Mechanism

By R. J. MEIJER. (From *Philips Technical Review*, Vol. 20, No. 9, 1958/59, pp. 245–262, 25 illustrations)

By applying a new design of drive mechanism to the hot-gas engine, Philips have made it possible to drop their idea of using one piston to perform both power and gas-transfer functions and to return to the thermodynamically more efficient system of separate power and transfer pistons. In this way and by the incorporation of a number of improvements in the design of regenerator, heater, etc., the engine has now been given a form that promises well for future development.

THE hot-gas engine is based on the same principle as the internal combustion engine, i.e., the compression at low temperature and expansion at high temperature of a given quantity of gas. The heating takes place, however, in an entirely different manner, the heat being supplied to the gas from outside, through a wall. For this reason the description "external combustion engine" is appropriate. Owing to the high thermal capacity of the wall, it is not, of course, possible to heat and cool the gas simply by rapid heating and cooling of the wall. Stirling realized as far back as 1817, however, that the gas temperature could be made to change periodically by causing a "displacer" piston to transfer the gas back and forth between two spaces, one at a fixed high temperature and the other at a fixed low temperature, as shown in Fig. 1. If the displacer piston (2) is raised, the gas will flow from the hot space (1) via the heater duct (6), the regenerator (5), and the cooler duct (4) into the cold space (3). If the displacer piston is now moved downwards, the gas will return to the hot space (1) along the same path. During the first transfer stroke the gas has to yield up a large quantity of heat, and an equal quantity of heat has to be taken up during the second stroke. The regenerator (5) is inserted between the heater duct and cooler duct in order to prevent unnecessary wastage of this heat, and comprises a space filled with porous material, to which the hot gas yields heat before entering the cooler; when the gas streams back, it takes up the stored heat again, prior to its entry into the heater.

The displacer system, which serves to heat and cool the gas periodically, is combined in the same cylinder with a power piston below the displacer piston, the power piston compressing the gas while it is in the cold space (3) and allowing it to expand while in the hot space (1). Since compression takes place at a lower temperature than expansion, a surplus of work results.

Although there are various methods of making the power and displacer pistons perform the required movements, the drive mechanisms used have certain disadvantages, especially in the case of large engines. Thus, the crankcase must be filled with the working gas under high pressure, to limit leakage of gas past the piston and also to preclude unnecessarily high downward forces on the drive mechanism. It is clear that considerable weight penalties are involved with such a pressurized crankcase. Particularly troublesome in large engines, this drawback becomes even more serious if it is desired to operate at very high pressures, in order to increase the specific power.

Bearing in mind the disadvantages of the displacer-piston system, with its separate power and transfer pistons, as embodied in the basic type of hot-gas engine, i.e., the Stirling engine, Philips developed in 1946 a double-acting system in which one moving body performs the functions both of power and transfer, thereby providing considerable mechanical simplification and eliminating the need for pressurizing the crankcase. This system has been successfully applied to their gas refrigerating machine, but, in the case of engines, gives rise to certain disadvantages in connection with lubrication, as the piston has to act as a moving gas-tight seal between a hot and a cold space, between which a large periodic difference in pressure occurs. Moreover, this type of engine is inferior, both thermodynamically and aerodynamically, to displacer-piston engines, owing to the fact that the variations in volume of the hot and cold spaces can no longer be freely chosen as regards their relative magnitude and phase.

As a result of further development, however, Philips have now designed an engine of the displacer-piston type which eliminates the inherent disadvantages of earlier types and also those of the double-acting type. Thus, the crankcase does not require pressurization and, by the embodiment of a new type of rhombic drive mechanism, has the additional advantage that even a single-cylinder engine can be balanced perfectly.

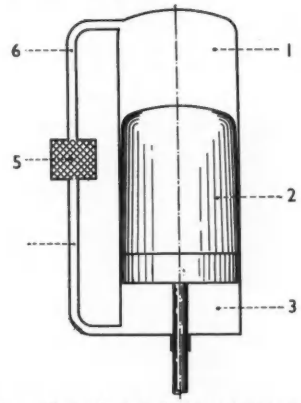


Fig. 1. **Principle of the displacer-piston system.**

Various engines have been built in accordance with this design, but this article is confined to details of the features and performance of a single-cylinder 40-hp engine. This engine, using hydrogen as the working fluid, has been designed for a pressure of 140 kg/cm² maximum and for a nominal speed of 1500 rpm, and has attained an overall efficiency for the engine alone, without auxiliaries, of 38% and a specific power of 120 hp per litre of swept volume, the specific weight being 5 kg/hp. Hydrogen was chosen as the working fluid because, owing to its low density, flow losses are not excessive, even at considerable engine speeds, and also because of its good heat-transfer characteristics. Helium can be used instead of hydrogen, but the overall efficiency is then somewhat lower.

THE RHOMBIC DRIVE MECHANISM

The new rhombic drive mechanism basically comprises twin cranks and connecting-rod mechanisms, identical in design and offset from the central axis of the engine. The cranks rotate in opposite directions and are coupled by

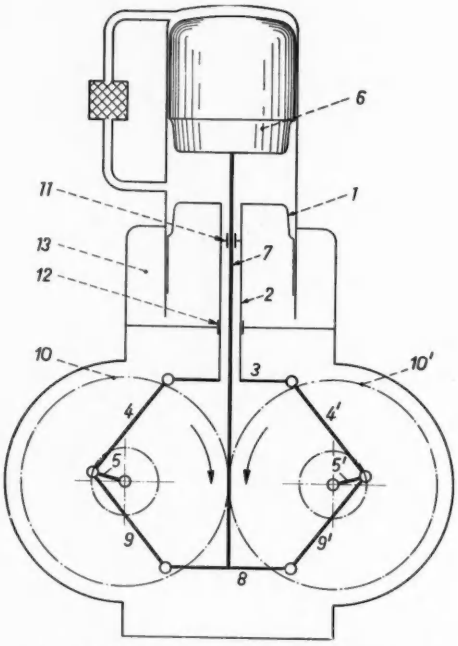


Fig. 2. Schematic diagram of the rhombic drive mechanism.

two gearwheels. The system is shown schematically in Fig. 2, in which a yoke (3) is fixed to the power piston (1) through a hollow piston rod (2). One end of the yoke (3) is linked by a connecting-rod (4) to a crank (5), and the other end by a connecting-rod (4′) to a crank (5′). The displacer piston (6) is actuated by a precisely similar arrangement, its rod (7), which passes through the hollow rod (2), having attached to it a yoke (8), linked to cranks (5) and (5′) by connecting rods (9) and (9′) respectively.

As connecting-rods (9) and (9′) have the same length as rods (4) and (4′), the two pairs of connecting-rods form a rhombus, only the angles of which vary when the system is in motion. Gearwheels (10) and (10′) ensure exact symmetry of the system at all times and, as the two crankshafts are geared together, the entire shaft output can be taken off either. The symmetry of the system and the coaxial arrangement of power-piston and displacer-piston rods make it an easy matter to avoid putting the crankcase under high pressure. The stuffing-box (11) for the displacer-piston rod is inside the hollow power-piston rod. One more seal, i.e., the stuffing-box (12) round the power-piston rod, is all that is necessary to form a comparatively small cylindrical chamber (13) under the piston, separate from the crankcase, and this " buffer " space can be filled with gas at the desired buffer pressure. The success of this arrangement depends essentially on the fact that the stuffing-box of the power-piston rod is subjected to no lateral thrust, as the horizontal components of the forces exerted by each pair of connecting-rods are exactly balanced at each yoke. The minimum permissible volume of the buffer space is determined only by the range within which it is desired to limit the pressure variations inside the chamber. In a multi-cylinder engine, the buffer chambers can be interconnected, permitting the volume of the individual spaces to be made even smaller.

The power and displacer pistons do not by any means move in simple harmonic motion, but it is found that a very good version of the Stirling cycle is obtainable. This might seem surprising, for on the face of it the use of the rhombic drive may appear to have restricted the freedom of choice with regard to the parameters of phase angle φ between the variations in volume of the hot and cold space and of amplitude ratio w, i.e., the ratio between their maximum volumes, both of these parameters playing a large part in the design of a hot-gas engine. However, more exact analysis of the new drive shows that it is, in fact, possible, by altering the offset of the crankshafts, the proportions of cranks and connecting-rods, and the ratio of power- and displacer-piston diameters, to vary these parameters over quite a wide range.

The rhombic drive has the important property of allowing the designer of an engine even with only one

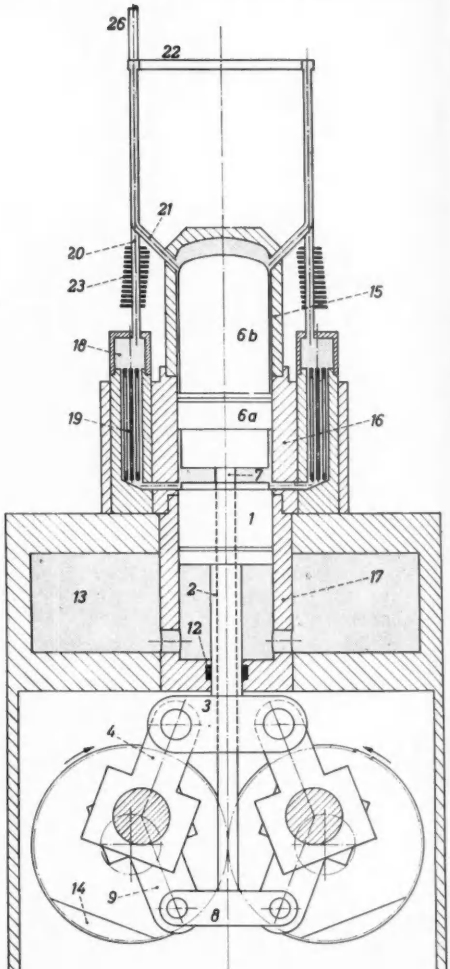


Fig. 3. Simplified cross-section of the experimental hot-gas engine with rhombic drive mechanism.

cylinder to obtain complete dynamic balancing of the forces due to the inertia of moving parts, and of the moments of these forces—" complete " in the sense that the fundamentals and all the higher harmonics are balanced.

In practice, use is made of two counterweights, mounted opposite each crankpin at a suitable radius, to create vertical inertial forces which exactly balance those of the moving masses of the two pistons, this being true even if the rotation of the crankshafts is not exactly uniform. In fact, the mass and offset of each counterweight are so chosen that the counterweight also serves to balance the crank and other eccentrically positioned moving parts. These counterweights (14) are shown in Fig. 3, which is a considerably simplified cross-section of the engine, not drawn to scale and omitting the burner and air preheater.

Other Constructional Details of the Engine

The cooler, regenerator, and heater all have an annular configuration, and are mounted around the expansion-compression cylinder, this arrangement making for compactness and low gas-flow losses. As shown in Fig. 3, the displacer piston consists of the piston base (6a) and a thermally insulated dome (6b), the piston base fitting like a conventional piston into the cylinder (16) at the level of the cooler. There is a small clearance between the dome (6b) and the cylinder wall (15) of the hot space, just sufficient to ensure that the two never come into contact. The buffer chamber (13) can be seen below the power piston (1). The major components of the rhombic drive mechanism shown in Fig. 2 (with the same symbols) are also shown in Fig. 3.

The design of the regenerator casing has undergone considerable modification, mainly with a view to eliminating the problems of thermal stress associated with earlier designs. In addition, the new design enables the whole assembly to be kept comparatively light, despite the high maximum pressure of the gas. The regenerator compartment (18) is split up into a series of cups, surrounding but not touching the displacer cylinder. Three tubes issue from each regenerator cup, their extensions forming the vertical heater tubes carrying the upward-streaming gas. Alternating with these, and connected to them by an annulus at the top, are downward-flow tubes leading to the head of the cylinder. With this design, it is possible to ensure that the lines of principal stress run substantially straight from the head of the cylinder (15) via the cylinder wall (16) to the base of the cylinder (17).

The design of the cooler has been adapted to that of the regenerator, the cooler housing (19) containing a number of tubes bunched together in groups to form cooler units, with the end of each unit protruding into one of the regenerator cups. As the tubes of each cooler unit are mounted with a sliding fit in the cooler housing, the regenerator cups are left free to undergo small longitudinal displacements as a result of expansion of the heater tubes.

The heater consists of a set of pipes (20) and a set of pipes (21), in close-packed configuration but with small clearances. The hot gases from the burner are blown between these tubes in a direction perpendicular to their length. The tubes of pipes (20) terminate inside the regenerator cups, and gas from the regenerator streams upwards through these tubes into the annulus (22), whence it is carried downwards by pipes (21), which are brazed into the hot end (15) of the cylinder. To improve heat transfer between the combustion gases and the working gas, a series of fins (23) is brazed to pipes (20). A tube (26) is fitted for insertion of a temperature probe, e.g., a thermostat element.

The heater is surrounded by the air preheater (Fig. 4), in which the air necessary for combustion enters the lower end of channels A_1 located around the outer perimeter of the preheater and then flows through spaces A between spirally curved partitions into channels A_2, around the inner perimeter, and thence upwards to the burner. The exhaust gases, which leave the burner at a temperature slightly higher than that of the heater, enter channels B_1 around the inner perimeter and flow via B, a second set of spiral spaces lying between the A spaces, in a direction opposite to that of the incoming air, to channels B_2 around the outer perimeter. It has been found possible to build a very compact preheater on this principle, with low resistance to air flow. Moreover, the preheater may be said to insulate itself, all the channels around its outer perimeter (A_1 and B_2) being near to the ambient temperature.

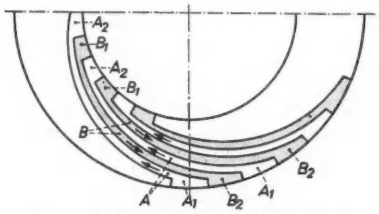


Fig. 4. Cross-section through air preheater.

The burner, of the swirl-chamber type, can be used in conjunction with a large number of fuels possessing widely different properties, such as coal gas, propane, butane, kerosene, diesel oil, and light fuel oil.

Regulation of Engine Output

The control system of the hot-gas engine is made up of two parts, as follows:—

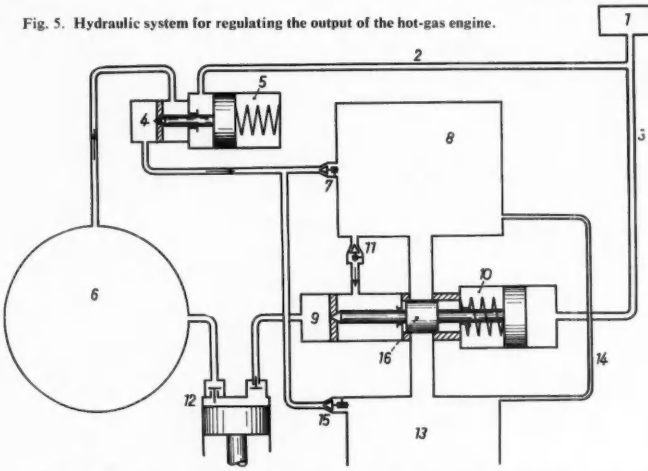
(1) A system for admitting gas to and withdrawing it from the engine in order to adjust the pressure to give the output required (i.e., the braking torque), while maintaining the preset speed of the engine constant.

(2) A system for controlling the fuel supply to the burner in such a way that the temperature of the heater remains steady when the power output (and hence the rate at which heat has to be supplied) is changed. For this purpose, control action is exercised by a thermostat, the temperature-sensitive element of which can be inserted in the stream of gas through one of the heater pipes, e.g., tube (26) in Fig. 3.

Regulation of pressure in the engine under consideration is effected by a set of hydraulically operated valves, a diagram of the system being given in Fig. 5. The governor (1), driven by the engine shaft, ensures that, at the nominal speed to which the engine has been adjusted to run, a certain oil pressure is maintained in pipes (2) and (3). If the engine slows down slightly in consequence of an increase in the braking torque, the governor raises the oil pressure in these pipes, with the result that the valve (4) in the feed device (5) opens up, and gas from the tank (6) passes via the feed-valve (7) into the space (8), which represents the cylinder of the hot-gas engine. As pressure inside the engine has risen accordingly, its power output increases. The injection of additional gas

continues until the engine speed has reverted to the original setting, whereupon valve (4) closes. If the speed increases slightly in consequence of a decrease in the braking torque, the governor causes the oil pressure in pipes (2) and (3) to drop, with the result that the valve (9) of the regulator (10) opens up, allowing gas from the cylinder to flow via the non-return valve (11) to the inlet of a small auxiliary compressor (12), when it passes into the tank (6). The release of gas from the engine continues until the nominal speed is attained, after which valve (9) closes.

Fig. 5. Hydraulic system for regulating the output of the hot-gas engine.



The auxiliary compressor gives a gas-tank pressure rather higher than the minimum pressure in the cylinder under conditions of full load. For increasing the engine output, therefore, it is possible to inject additional gas via valve (7) until the full power is developed, this adjustment taking place very rapidly. When it is a question of reducing the output, for example from full power, the auxiliary compressor initially performs no function, because gas from the cylinder returns to the tank via valves (11) and (9) under the excess pressure in the cylinder, continuing until the maximum pressure in the cylinder has dropped to the tank-pressure value. This also happens very quickly. If, however, the cylinder pressure is to be lowered still further, then the auxiliary compressor must function, and thereafter this determines the speed of response. If a sudden decrease in the load (e.g., sudden removal of the whole braking torque) is not to result in racing of the engine, the compressor required would have to be very large. This difficulty has been overcome by incorporating an additional regulating mechanism. Besides opening and closing valve (9), regulator (10) actuates a slide throttle (16) which offers the gas a direct path between cylinder and buffer chamber, the escape of gas being large or small in accordance with the magnitude of the change in the load. It is clear that this gas escape path is equivalent to a leak past the power piston, and causes a certain decrease in the useful power delivered by the engine. Because the action of the slide throttle has an almost instantaneous effect, a very small auxiliary compressor is adequate.

In consequence of the direct connection between cylinder (8) and buffer space (13) when the power of the engine is being reduced, the buffer pressure likewise adjusts itself almost immediately to the correct value. This quick readjustment is highly desirable, since it limits unnecessary asymmetrical thrust on the drive mechanism. A similar purpose is served by valve (15), which prevents the buffer pressure lagging too much when output is suddenly raised to a much higher value. If the value from which it is raised is so low that the mean pressure in the cylinder is less than the tank pressure, gas from the tank will pass directly into the buffer chamber via valves (4) and (15).

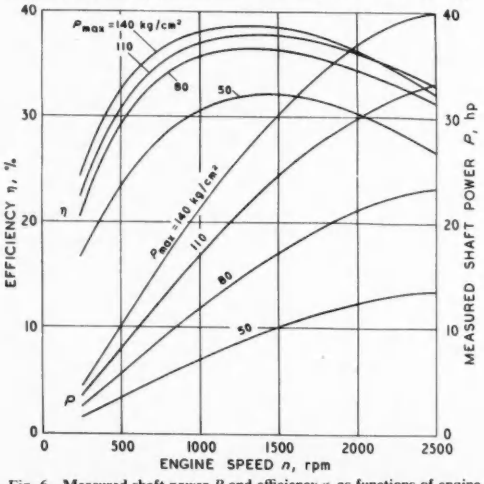


Fig. 6. Measured shaft power P and efficiency η as functions of engine speed n for various values of maximum pressure p_{max}.

Engine Data and Test Results

Tests were conducted on this single-cylinder hot-gas engine incorporating the new rhombic drive mechanism, the relevant engine data being as follows:—

Cylinder bore	88 mm
Power-piston stroke	60 mm
Nominal engine speed	1500 rpm
Mean piston velocity at 1500 rpm	3 m/sec
Maximum permissible pressure p_{max}	140 kg/cm²
Mean pressure p	105 kg/cm²
Compression ratio	2·0
Nominal cooling-water temperature	15°C
Nominal heater temperature	700°C
Working fluid	Hydrogen
Fuel	Light fuel oil

The values of efficiency derived from measurements of brake horsepower and specific fuel consumption are based on the use of a fuel with a nett calorific value of 10,000 kcal/kg and relate to the engine without auxiliary equipment, which, apart from the usual pumps and fans for forced oil feed and cooling, comprises the small regulating compressor already mentioned and a blower for the burner. Of all these auxiliaries, the blower absorbs the highest power, i.e., from 1 to 2% of the engine output.

Measurements were made at four different pressure

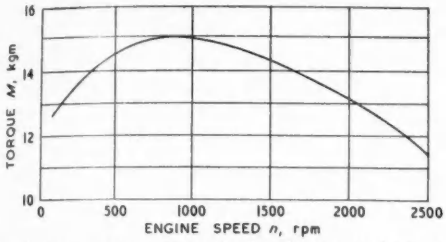


Fig. 7. Measured torque M as a function of engine speed n for the highest permissible pressure level p_{max} of 140 kg/cm².

levels, corresponding to p_{max} values of 50, 80, 110, and 140 kg/cm² and at six different engine speeds n for each of these levels, i.e., 250, 500, 1000, 1500, 2000, and 2500 rpm. In Fig. 6 the measured power P and overall efficiency η are plotted as functions of engine speed n, and it will be seen that a power of up to 40 hp can be developed and that the overall efficiency has a maximum value of 38%. Fig. 7 shows torque M as a function of engine speed n for the maximum working pressure P_{max} of 140 kg/cm², and serves to show the unusual flexibility of the engine, inasmuch as torque varies only slightly (from 11·5 to 15 kgm) over a very wide range of speeds. Equally remarkable is the fact that, as shown in Fig. 6, there are only small variations in efficiency over a considerable range of speeds and pressures.

It should be mentioned that tests have shown that the engine achieves its highest efficiency at almost maximum

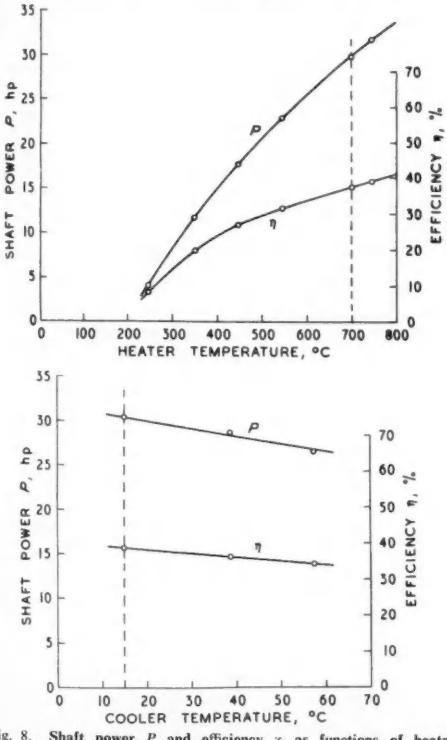


Fig. 8. Shaft power P and efficiency η as functions of heater temperature, and of cooler temperature for an engine speed of 1500 rpm and a p_{max} value of 140 kg/cm².

mean effective pressure. This peak value of pressure is not determined by a " smoke limit ", as in a diesel engine, but simply by the strength of the engine casing. In making such a comparison, however, it should be emphasized that values of mean effective pressure p_e alone are quite useless (and so, too, is specific power output) as a yardstick for comparing hot-gas engines with internal-combustion types from the viewpoint of bulk. A better criterion is specific weight and, although few special measures were taken to keep down the weight of this particular experimental engine, its specific weight, as already mentioned, is only 5 kg/hp.

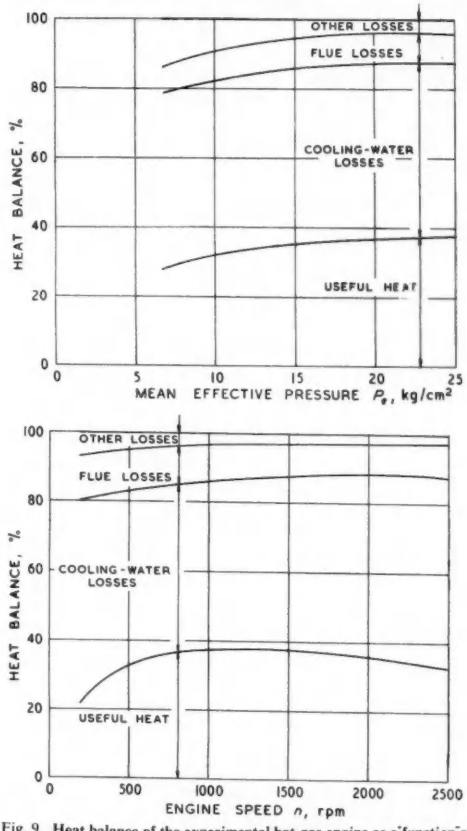


Fig. 9. Heat balance of the experimental hot-gas engine as a function of mean effective pressure p_e at a speed n of 1500 rpm, and of speed n at a p_{max} value of 140 kg/cm².

To summarize the extreme values obtained for various measurements, it may be said that the maximum shaft output is 40 hp at 2500 rpm with a p_{max} value of 140 kg/cm², corresponding to a maximum specific power output of 120 hp/litre of swept volume. Maximum torque M and maximum mean effective pressure p_e are obtained at 800 rpm, with a p_{max} value of 140 kg/cm², the respective values being 15 kgm and 26 kg/cm². Maximum overall efficiency η is 38%, corresponding to a shaft output of about 28 hp at approximately 1350 rpm, with a p_{max} value of 140 kg/cm², the minimum specific fuel consumption being 165 gm/hp-hr.

(*Concluded on page 264*)

U. S. A.

Designing Bimetal Elements for Maximum Performance

By C. F. Alban and C. C. Perry. (From *Machine Design*, Vol. 31, No. 8, April 16, 1959, pp. 143–148, 8 illustrations)

In many applications of thermostatic bimetal elements, the capacity of the bimetal for performing mechanical work is of very great importance. A rather common practice in the development of bimetal-actuated devices is to design the operating mechanism first and then try to fit a bimetal element to the application. In such cases, load, deflection, and temperature changes are generally specified. The problem then becomes one of designing a bimetal element of practical proportions and of minimum volume for the lowest cost, and this is always achieved by adjusting the dimensions of the element.

In some cases, where the original performance specifications of the bimetal-actuated device are exacting, the element so designed will be disproportionate. Thus, it may be too long to fit the available space, it may be so thin that it lacks mechanical ruggedness and stability, it may be too thick for the required forming and stamping operations (excessive thickness also leads to slower response to thermal transients), or it may be so short and wide that it will not perform according to theory and is subject to inaccuracies from mounting effects.

These problems can be overcome by several methods outlined in this article. For example, the type of bimetal element can be changed from a simple cantilever to a triangular cantilever to take advantage of its greater capacity for work per unit volume; alternatively, a different bimetal material having a higher work index can be used, or the specific deflection of the element can be adjusted (at the expense of increased bimetal volume). If these methods fail to improve bimetal proportions, performance specifications can then be adjusted.

Disproportionate bimetal elements most frequently arise from applications which require a combination of very high deflection and low force, or extremely low deflection and high force, to be achieved in either case by a small temperature change. The following remedial techniques are recommended for overcoming such problems :—

(1) Changing the design (where possible) of the operating mechanism of the bimetal-actuated device, to reduce the work requirements and more nearly balance the force and deflection specifications.
(2) Increasing the temperature change available to perform the action.
(3) Selecting the most suitable type of thermostatic bimetal material.
(4) Selecting the optimum type of element (straight cantilever, trapezoidal cantilever, simply supported beam, U-shaped element, coil, etc.) for the application.
(5) Adjusting the specific deflection, to bias the performance of the element (at a premium in increased volume) in the direction of the unbalanced force and deflection requirements.

With regard to specific deflection, it should be noted that the work produced by a bimetal element as the temperature is changed from T_1 to T_2 depends on the mode of operation, i.e., on the load-deflection characteristics of the installation, as illustrated in Fig. 1. For any particular temperature change, the final operating condition of the bimetal can be represented by a point on the diagonal line, which has, for convenience, been scaled in units of the specific deflection m.

Bimetal operating conditions change from those at the origin to those represented by a point on the diagonal in the *P-D* plane, the mechanical work ouput being the area under this path. For example, complete restraint of the bimetal element merely allows the operating point to travel up the ordinate. In this instance, the deflection is zero and there is, of course, no area under the curve and therefore no work done. It can also be seen that, with free deflection, the operating point moves outwards along the abscissa from the origin but, as no force is developed, the area under the curve and the work are again zero.

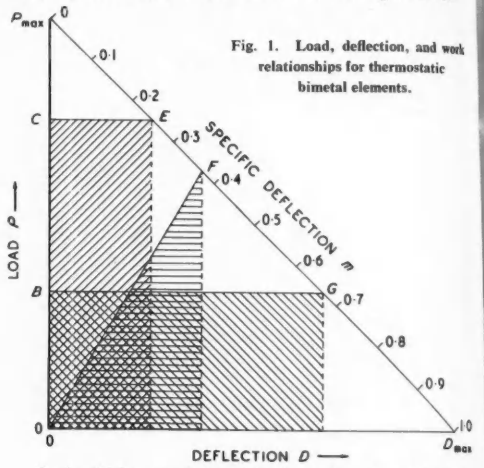


Fig. 1. Load, deflection, and work relationships for thermostatic bimetal elements.

It should be noted that this discussion is restricted to those cases which involve development of a force with temperature change, and the calculations for work do not include the effects of static, unchanging pre-loads. If, for example, a horizontal cantilever-mounted bimetal strip has a dead weight suspended from its free end, subsequent temperature changes will cause a corresponding change in deflection precisely equal to the free deflection of the element, independent of the weight, as long as the maximum allowable stress is not exceeded. Thus, the super-position theorem common to beam-analysis methods conveniently permits separate treatment of initial mechanical loading and thermally developed loads.

Bimetal elements which are designed to pick up gravity loads, overcome set preloads, or develop the force to operate against a constant resistance produce in the *P-D* plane rectangular work areas such as those delineated under paths *OCE* and *OBG* in Fig. 1. A constant-rate spring load produces a triangular work area such as that under *OF*. It is apparent that, for any final operating point on the diagonal line, maximum work will be done in reaching that point if the operating path outlines a rectangular work area (except, of course, for over-centre spring arrangements).

Simple Cantilever Bimetal Elements

In the case of a constant load P, and assuming the use of a strip of unit length L, width b, and thickness t, the equation for work W is

$$W = PD = K_{PS}K_{DS}{}^2(\Delta T)^2btL(1 - m)m \quad .. \quad (1)$$

where D is the deflection of the strip, m is the specific

deflection, ΔT is the temperature change [°F], and K_{PS} and K_{DS} are respectively the torque constant and the deflection constant of the strip. Eq. (1) shows that the mechanical work output of a thermostatic bimetal strip is proportional to $K_{PS}K_{DS}^2$ (which may be termed the work index, a fundamental property of the bimetal material), the square of the temperature change, the volume of the bimetal element, and a function of the specific deflection m. Further study of eq. (1) reveals that mechanical work is zero when m is either zero or unity, corresponding to conditions of complete restraint or free deflection respectively, and confirms the previous conclusions deduced from the P-D diagram. Maximum mechanical work occurs at $m = 0{\cdot}5$, as can readily be proved by differentiating eq. (1) with respect to m and setting the result equal to zero.

Similarly, for applications in which the bimetal deflects a constant-rate spring with temperature change, the P-D work area equals $PD/2$, and

$$W = \frac{K_{PS}K_{DS}^2(\Delta T)^2btL(1 - m)m}{2} \quad .. \quad (2)$$

Since the numerical factor of $\frac{1}{2}$ is independent of m, differentiation of this work equation produces the same result as before, i.e., for maximum work m should be equal to 0·5. It can also be shown that, for non-linear springs having load-deflection characteristics expressible by a relationship of the form $P = KD^N$, where K and N are constants, a specific deflection of 0·5 will still be required for maximum work. It should be noted that, for a particular force and deflection requirement and specific deflection, the volume of bimetal element necessary to perform the task is the same, regardless of the path in the P-D plane. In other words, the same volume will be necessary, irrespective of whether the element develops and moves a constant force a given distance or compresses a spring to the same maximum force in the same distance.

Bimetal Coils

In the case of bimetal coils, the mechanical work W can be expressed as

$$W = 0{\cdot}01742K_{PC}K_{DC}^2(\Delta T)^2btL(1 - m)m \quad .. \quad (3)$$

where K_{PC} and K_{DC} are respectively the torque constant and the deflection constant of the coil. Eq. (3) is basically similar to eq.(1), and both can be compared for absolute magnitude, since there are at least theoretical relationships between K_{PC} and K_{PS}, and between K_{DC} and K_{DS}, for any bimetal.

It can be shown that a coil will produce about 50% more work than a cantilever-mounted straight strip of the same active volume. In applications involving very small displacements (with no problems in converting rotary to linear motion) the use of a coil instead of a straight strip could result in a measurable saving in bimetal volume, if the coil dimensions are within a practicable range. The production, mounting, and assembly costs of coils, as compared with those of straight strips, must naturally be considered in making any overall cost comparison.

Simply Supported Beam Elements

Design situations embodying comparatively large forces and small deflections also suggest the use of a simply supported straight beam, since such a beam is an inherently high-force, low-deflection member. The corresponding work equation for a beam of this type is

$$W = K_{PS}K_{DS}^2(\Delta T)^2btL(1 - m)m \quad .. \quad (4)$$

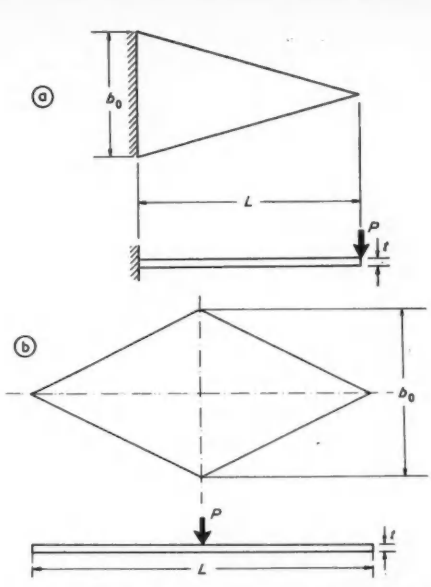


Fig. 2. Simply supported constant-strength triangular and rhombic beams.

In other words, the capacity of the simply supported beam for mechanical work is similar to that of a cantilever beam of the same dimensions, as expressed in eq. (1). It should, however, be noted that, other things being equal, the simply supported beam produces four times the force P and one-quarter of the deflection D of a cantilever element.

When attempting to achieve maximum work per unit volume, consideration should be given to the simply supported constant-strength triangular beam (Fig. 2a) or the rhombic beam (Fig. 2b), both of which are characterized by uniform bending stress along their lengths when loaded as shown. In the case of the triangular beam with a concentrated load at the free end, both the bending moment and moment of inertia are linear functions of the distance along the beam.

Triangular Cantilever Elements

The triangular or rhombic design is considered the optimum in efficiency where a maximum allowable stress is the limiting factor, since all surface fibres are stressed to the same extent. The advantages of this design are most pronounced, however, for a beam in which all or most of the stress is due to mechanical loading. In thermostatic bimetal elements, a portion of the stress is generated by differential expansion of the component metals. Since the latter effect is uniform along the length of the beam and is independent of the width, a triangular design will not modify thermal stresses. Thus, any gains to be derived from the triangular shape will be realized only with respect to mechanical loading.

In terms of free-deflection response as a thermostatic bimetal element, a triangular beam theoretically has the same characteristics and produces the same deflection for a particular temperature change as a straight-sided or rectangular beam of the same length and thickness. Actually, deflections would not be exactly the same, be-

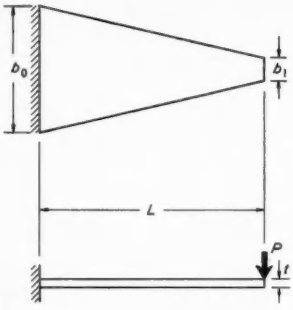


Fig. 3. (left) Modified triangular beam with sufficient width at the free end to support a load.

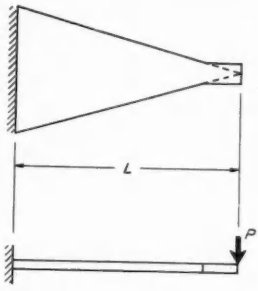


Fig. 4. (right) Trapezoidal cantilever beam.

cause of differences in cross-curvature effects between the two types. The relationships developed in this article have ignored such effects but, for precision results, experimental elements should be fabricated and tested before going into production.

The work equation of a triangular cantilever element can be expressed as

$$W = \tfrac{2}{3} K_{PS} K_{DS}^2 (\Delta T)^2 b_0 t L(1 - m)m \quad .. \quad (5)$$

In this case, the work capacity is two-thirds that of a rectangular beam of the same length and thickness, but the work per unit volume is 33% greater than for the corresponding rectangular beam. Other generalities previously derived remain unaffected. For example, the specific deflection of the triangular beam should still be 0·5 for a bimetal element of minimum volume. From a practical viewpoint, the gain in work per unit volume to be realized from using a triangular beam is slightly less than that calculated here, because of the necessity of providing sufficient width at the free end of the beam to support the load. An actual beam might have an appearance such as that shown in Fig. 3, the modified contour producing only a very small effect on stiffness.

Trapezoidal Cantilever Elements

As a compromise, use can be made of a trapezoidal beam (Fig. 4), the work capacity of such a beam being

$$W = \frac{K_{PS} K_{DS}^2 (\Delta T)^2 b_0 t L(1 - m)m}{3U} \quad .. \quad (6)$$

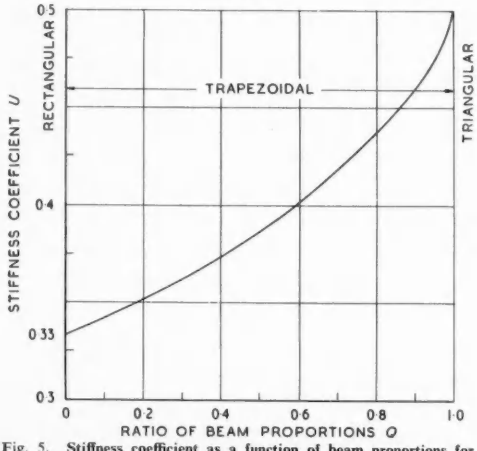


Fig. 5. Stiffness coefficient as a function of beam proportions for trapezoidal beams.

where U is the stiffness coefficient for trapezoidal beams. Values of U are taken from Fig. 5 and are functions of the ratio of beam proportions Q, where $Q = 1 - (b_1/b_0)$.

As shown in Fig. 5, when $Q = 0$, $U = 0{\cdot}333$, and the trapezoidal beam becomes a rectangle, eq. (6) reducing to eq. (1). Similarly, when $Q = 1$, $U = 0{\cdot}5$, and the beam becomes a triangle, eq. (6) reducing to eq. (5).

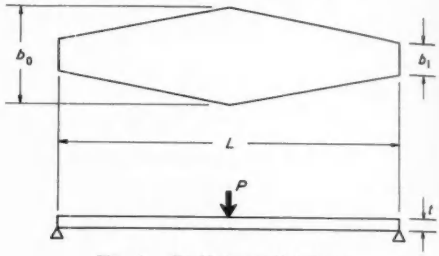


Fig. 6. Double-trapezoidal beam.

Eq. (6) shows that, as Q varies from zero to unity, and U from 0·333 to 0·5, the work capacity of the trapezoidal beam varies from that of the straight-sided rectangular beam to that of the triangular beam. Thus, any volume saving from zero to 25% is theoretically possible.

Simply Supported Double-Trapezoidal Elements

In applications involving a large force and a small deflection, use can be made of a double-trapezoidal beam (Fig. 6), the work capacity of which is the same as that expressed in eq. (6) for a trapezoidal cantilever element. However, it should be noted that the double-trapezoidal element develops four times the force P and one-quarter of the deflection D of a trapezoidal cantilever element of equal length and thickness.

Conclusion

From eqs. (1) to (6), it will be seen that, to obtain maximum mechanical work from a thermostatic bimetal element, it is essential to select a bimetal with the maximum work index, to employ the largest permissible temperature change, to use the greatest practical volume, and to design for a specific deflection of 0·5. The remaining parameters are not, in many design applications, subject to adjustment at will.

Generally, a specification involves predetermined load, deflection, and temperature change, the design problem being to select the optimum bimetal type and the size, shape, and proportions of the bimetal element. However, since the total bimetal volume required for any design varies directly with the thermally developed mechanical work and inversely with the square of the temperature change, attention should always be given to minimizing the work and maximizing the temperature change to minimize the volume.

Ultrasonic Machining of Hard and Brittle Materials

By L. D. Rosenberg and D. F. Iakimovich. (From *Vestnik Mashinostroyeniya*, Vol. 39, No. 2, February 1959, pp. 51–55, 7 illustrations).

Ultrasonic machining is characterized by the relative ease with which hard and brittle materials can be machined, by the high accuracy and finish of the machined surface, and by the absence of any deleterious effects on the structure of the material. During the actual machining, the tool is subjected to a reciprocating motion of high frequency and small amplitude, while an abrasive slurry is conducted to the working zone, removing fine particles from the workpiece. Wear takes place mainly on the end face of the tool, so that its cross-section remains practically unaffected.

The rate of material removal depends on many parameters, the most important of which are the amplitude and frequency of tool vibrations, the hardness and grain size of the abrasive, the concentration of abrasive in the slurry, the viscosity of the slurry, the force with which feed is applied, the shape of the tool, the area of the surface to be machined, the depth of penetration, and the material of the workpiece.

Some data on material removal and tool wear for various workpiece materials are given in Table I. These data are based on tests with a machine rated at 700 W, a frequency of vibration of 25 kcs with an amplitude of 0·076 mm, a tool of cold-rolled steel, 12·7 mm in diameter, and a depth of penetration of 12·7 mm, the abrasive used being 320-grit boron carbide.

Table I: Rate of Workpiece Removal for Different Materials and Tool Wear

Material	Workpiece Removal Rate [mm³/min]	Tool Wear [mm³/min]
Glass	320	1·6
Germanium	240	1·2
Silicon	240	1·2
Ferrite	240	1·2
Mother-of-pearl	240	1·2
Porcelain	190	1·3
Quartz	140	2·8
Synthetic ruby	65	32
Sintered boron carbide	48	16
Tungsten carbide	29	29
Quenched tool steel	22	22

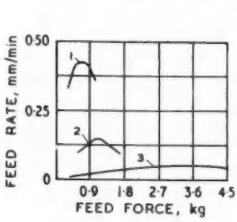
Fig. 1 illustrates the relationship between feed rate and feed force, this force being generally between 0·1 and 4·5 kg, depending on the workpiece material. As mentioned above, the rate of removal also depends on the abrasive grain size, increasing as the latter increases.

The accuracy and surface finish of the machined part mainly depend on the abrasive grain size (Table II), but also on the accuracy and rigidity of the machine itself. Tool wear impairs machining accuracy, so that, to obtain high accuracy, it is sometimes necessary to change tools and to let a roughing cut be followed by a finishing cut. In some cases, this inconvenience may be overcome by the use of a stepped tool, particularly for machining through-holes in components of small thickness.

The ratings of ultrasonic machines at present available range from 50 W to 2·4 kW. The largest size of hole that can be produced on any particular machine depends on its rating, whereas the smallest size depends on the rigidity of the machine and on the sensitivity of the feed mechanism. Generally, hole sizes range from 0·15 to 90 mm in diameter, as a further increase in hole diameter would require a larger transducer, involving a number of technical difficulties. Frequencies usually range between 18 and 25 kcs because, in this range, noise generation is low and the head can be of compact design.

Table II: Effect of Abrasive Grain Size on Accuracy and Surface Roughness

Grain Size [Grit No.]	Machining Accuracy [microns]	Surface Roughness [microns, r.m.s.]
240—420	±50	0·46—0·64
600—800	±13	0·25—0·38
1000	± 5	0·2



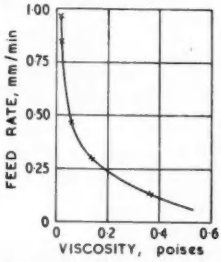


Fig. 1 (left). **Relationship between feed rate and feed force, using a tool with a diameter of (1) 6·35 mm, (2) 12·7 mm, and (3) 38·1 mm.**
Fig. 2 (right). **Relationship between feed rate and the viscosity of the abrasive suspension, using a circular tool of 6·35 mm diameter.**

The maximum depth of penetration, roughly equal to one or two hole diameters, is limited by the difficulty of feeding the abrasive slurry to the cutting zone. In this connection, it should be mentioned that the tool may have to be provided with holes and channels, to permit the abrasive to reach the locations of actual cutting.

To avoid harmful transverse vibrations, the tool should be so designed that its centre of gravity lies in the axis of the head. Moreover, the tool should be as short and as rigid as possible, and the thickness of its walls and of any projections on its face should be at least five times the abrasive grain size; otherwise, the wall is quickly punctured and worn away.

The abrasive may be boron carbide, silicon carbide, or corundum. Boron carbide is the most suitable from the point of view of its cutting properties; also, it is easily wetted by water and, owing to its low specific gravity, remains satisfactorily in suspension. It is, however, the most expensive. The carrier medium, usually water, feeds the abrasive to the cutting zone, washes away the loose particles, and also acts as a coolant. The best concentration of abrasive in the carrier medium is 30% by volume. The viscosity of the slurry has a great influence on the rate of metal removal, as demonstrated in Fig. 2.

The use of ultrasonic methods of machining germanium and silicon gives production rates which are several times higher than those of conventional methods, while the saving in material when producing components of glass and quartz sometimes ranges from 20 to 50%. However, it should be noted that ultrasonic machining methods have certain disadvantages in practice, particularly in connection with the reliability of equipment and the difficulty of tool-setting and tool-changing. Consequently, of the many different types of ultrasonic machines developed in Russia and in other countries, a characteristic feature of the latest models is increased accuracy, versatility, and capacity. Thus, some of the newest machines incorporate a swinging head to facilitate setting up, while others also incorporate a swinging table. In some

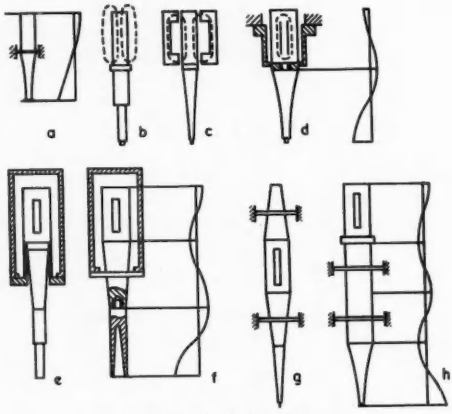


Fig. 3. Types of vibrating systems.
(*a*) Half-wave system. (*b*) System with two half-waves and open magnetic circuit. (*c*) Yoked system with two half-waves. (*d*) System with two half-waves and supporting quarter-wave cup. (*e*) System with three half-waves, supporting quarter-wave cup, and transition piece. (*f*) System with three half-waves and transition piece. (*g*), (*h*) Systems with four half-waves.

models, components are machined successively in two fixtures attached to the table, rough-machining being carried out with a coarse abrasive in the first position, and finish-machining with a fine abrasive in the second position. Each abrasive bath is fed from its own pump.

The vibrating system of the head makes use of magnetostrictive transducers, generally nickel, owing to the scarcity of other suitable metals and the complex nature of their heat treatment. In small-size heads, half-wave systems are employed (Fig. 3a), while a small-size open magnetic system (Fig. 3b) or a yoked transducer (Fig. 3c) is generally used in low-power heads. In more powerful heads (above about 400 W), two-core transducers are used (Fig. 3d).

In full-wave systems, a small flange is brazed to the end of the transducer, the horn (usually of a length corresponding to half a wavelength) being screwed into the flange. In systems using three half-waves (Figs. 3e and 3f), a half-wave transition piece is brazed to the transducer, into which the removable part of the horn is screwed. Typical systems using four half-waves are shown in Figs. 3g and 3h.

The horns used are either of stepped construction or their diameters taper in accordance with either an exponential law or a hyperbolic-cosine law. Stepped horns are very simple to design and use, and can be employed successfully for machining glass, germanium, etc., i.e., in low-amplitude work, where there is no risk of breaking the horn at the stress-raiser, i.e., the step. Exponential-type horns give good results for drilling small-diameter holes and at high amplitudes, e.g., in cutting hard alloys. The hyperbolic-cosine type of horn is intermediate between the exponential and stepped types. Instead of a horn, a steel rod may be employed for transmitting vibrations from the transducer to the tool, this being specially useful when carrying out ultrasonic machining in relatively inaccessible areas.

In nearly all ultrasonic machines, the head is fed vertically by means of a carriage, the guides of which must fulfil very strict requirements as regards accuracy and low friction, roller-type guides generally being used for this purpose. Feed can be effected either pneumatically or hydraulically, or by gravity or spring-loading. The table of the machine must permit accurate setting-up movements, and the table guides must be protected against overflow of abrasive. To prevent abrasive from settling on the surface of the table, drainage channels with a pronounced slope are provided; alternatively, drainage holes can be drilled in the table.

On the basis of industrial requirements in Russia, it is considered that attention should be directed towards the following major aspects of design in connection with ultrasonic machines:—

(1) Developing designs and manufacturing methods for ultrasonic heads of high accuracy and rigidity.
(2) Developing fixtures enabling tools to be mounted firmly in the required position, without the need for high clamping forces, which have an adverse effect on the feed mechanism.
(3) Improving the design of the feed mechanism, so as to provide increased sensitivity and satisfactory control.
(4) Developing a suitable method of directing the abrasive slurry into the actual cutting area.
(5) Increasing the accuracy of the co-ordinate motions of the machine.
(6) Developing equipment capable of drilling holes of less than 0·15 mm and more than 90 mm in diameter.

The ready availability of reliable mass-produced ultrasonic equipment will not only facilitate rapid assimilation by industry of this technique and the accumulation of the necessary production experience, but will also make it possible to discover far more quickly new fields in which it can be applied. It should, however, be mentioned that a thorough investigation into the physics of the process is also of great importance, in order to explain the laws governing the rate of removal of the workpiece material, and the consequent possibility of defining the most suitable lines of investigation for effecting further increases in productivity and reductions in tool wear.

Investigations into Techniques for Producing Cast Silicon Components

(*Concluded from page 245*)

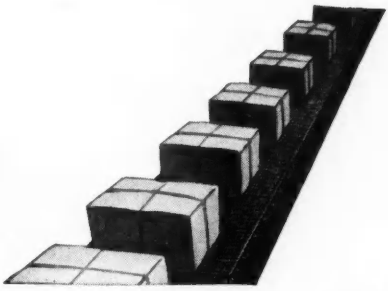
20 kcps for drilling, and 23 kcps for slotting, in all cases with a boron carbide slurry.

After machining, the testpieces were submitted to bending and compression tests, the maximum bending stress being found to be 1200 kg/cm² and the average bending stress 1000 kg/cm², while the corresponding values for compressive stress were 650 and 600 kg/cm² respectively. The great discrepancy in these results, especially in the case of bending stresses, may be explained by the presence of slag inclusions and surface defects in some of the components.

For observation of microstructure, testpieces were cut ultrasonically and were then ground and polished by boron carbide abrasive wheels. For etching, a 30% solution of sodium hydroxide, or a mixture containing 3 parts of 48% concentrated hydrofluoric acid, 5 parts of 70% concentrated nitric acid, 3 parts of acetic acid, and 2 parts of a 3% aqueous solution of mercuric nitrate, was used. The silicate inclusions appeared after treating the specimens for 3 hr with chlorine, followed by etching for 10 min with concentrated hydrofluoric acid. Examination showed that the microstructure of the cast silicon is polyhedral, with a thin lattice of silicon dioxide, silicon carbide, or iron carbide inclusions at the grain boundaries.

LIFT WITHOUT SLIP

with Goodyear rough top conveyor belting



GOODYEAR CONVEYOR BELTING
TYPE D ROUGH TOP

A. Thick top cover with deeply impressed gripping pattern.

B. Carcass of 28 or 32 oz. high quality cotton duck.

C. Thickness of hard wearing bottom cover or friction surface to suit service.

A DEEP REGULAR pattern, exclusive to Goodyear, enables this belting to take a firm grip on sacks and on smooth articles, such as cartons. The pattern, plus a choice between soft and hard top cover to suit the needs of the installation, ensures freedom from slip on slopes up to 30° inclination.

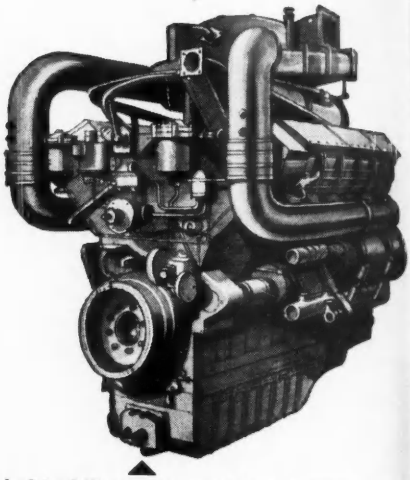
Goodyear Rough Top belting, like all styles of conveyor belting in the Goodyear range, is solely designed for a specific type of duty, and to give long, reliable service at lowest cost per ton carried.

GOODYEAR

INDUSTRIAL RUBBER PRODUCTS

CONVEYOR BELTING · TRANSMISSION BELTING · HOSE · V-BELTS

MAYBACH POWER MADE IN BRITAIN

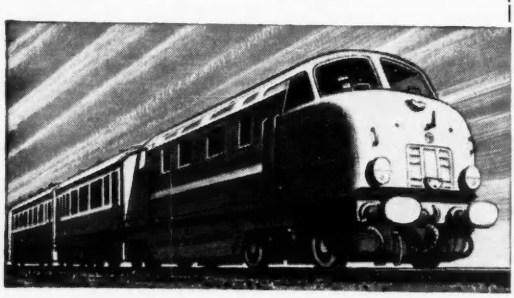


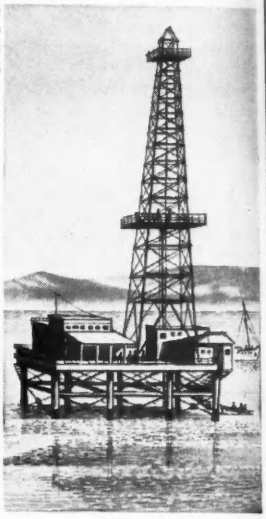
Typical of the MD range of engines is this Type 650 12-cylinder supercharged model with cylinders arranged in 'V' formation.

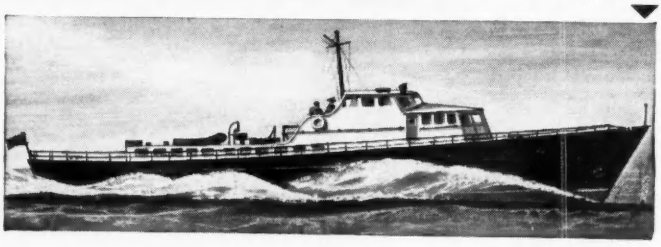
◀ Railway Traction 220-2,000 B.H.P.

Industrial Plant 220-1,750 B.H.P. ▶

Marine 220-3,000 B.H.P.







Bristol Siddeley have the exclusive manufacturing and selling licence in the United Kingdom for the world-famous Maybach MD range of In-line and 'V' form diesel engines. These diesels range from 4-cylinder engines of 220 hp to 16-cylinder engines of 3,000 hp. They have an outstanding record of performance and reliability over millions of miles on railways throughout the world, and are widely used for marine propulsion and industrial power generation of all kinds.

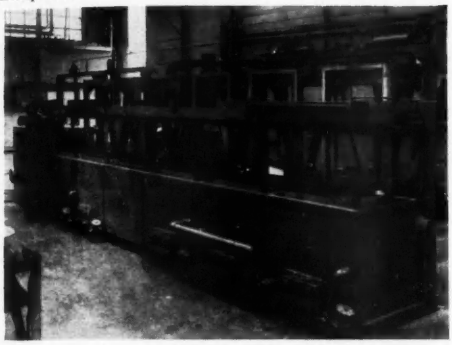
BRISTOL SIDDELEY **Maybach** **DIESEL ENGINES**

BRISTOL SIDDELEY ENGINES LIMITED, COVENTRY, ENGLAND

British Industrial Developments

Automatic Metal Pretreatment Plant

The "Agi-dip" fully automatic multi-stage pretreatment plant, introduced by the Electro-Chemical Engineering Co. Ltd., of Woking, Surrey, can be used for various types of cleaning and process treatments, including pickling and phosphating, on a wide variety of ferrous and non-ferrous metal components. The parts to be treated are loaded into baskets, which are then automatically passed through agitated immersion stages, and trichlorethylene vapour degreasing, spray rinsing, and drying sections can be incorporated into the sequence, if required.



Agitation is carried out by means of a reciprocating pneumatic arrangement with adjustable stroke amplitude and frequency. Double-acting air cylinders permit the work platforms to be driven down into the solutions at a faster rate than the freely falling components, thus effecting complete separation of tightly packed parts. The work is transported through the sequence by means of an index beam conveyor controlled by a timing mechanism, which can also operate automatic loading and unloading platforms, to link the plant with a shop conveyor, only one operator being required for the plant under normal conditions.

Vertical Batch Furnace

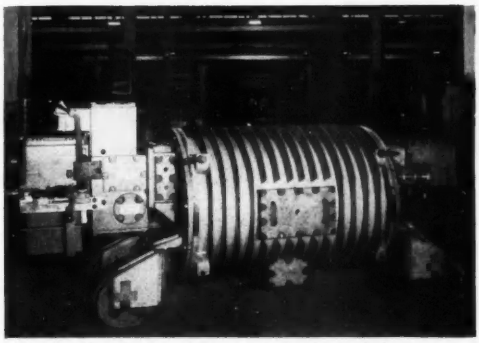
Designed and constructed by Ferro Enamels Limited, of Wolverhampton, a new vertical batch furnace is claimed to have a remarkably high thermal efficiency. Essentially, the furnace is a tower, the casing being mounted on four legs, so that the bottom of the furnace is about 9 ft above the shop floor. The ware to be fired is hung by means of alloy hooks from coat hangers mounted on an alloy suspension bar, arranged to be picked up by two heat-resisting alloy rods which drop through the furnace roof down to the loading level. Outside the furnace roof, the lifting rods are connected, by means of a yoke, to roller-type chains, which travel over sprockets and are then connected to an electric hoist. Access to the furnace is by means of two insulated sliding doors on the bottom face of the furnace casing. At floor level the suspension bars are supported on a transfer frame, which is made to carry two bars, so that one station can be used to load the furnace while the other is being used for unloading and reloading.

The furnace is electrically heated by elements displaced over the sidewalls only, and has an installed load of 200 kW, control being effected in two zones, one in the top half of the furnace and the other on the bottom half. The effective inside working clearances are 8 ft long by 10 ft high by 2 ft wide and, by virtue of its design, the furnace is ideal for firing multiple units of long section, such as trough reflectors. However, a variety of work, such as panels, refrigerator liners, and cooker parts, can also be fired efficiently. Owing to its ability to accommodate long units in a hanging position the furnace represents a much more flexible unit than a batch furnace. It is also economical in the use of available floor space, and the initial and operating costs are said to compare very favourably with those of conventional batch-type furnaces.

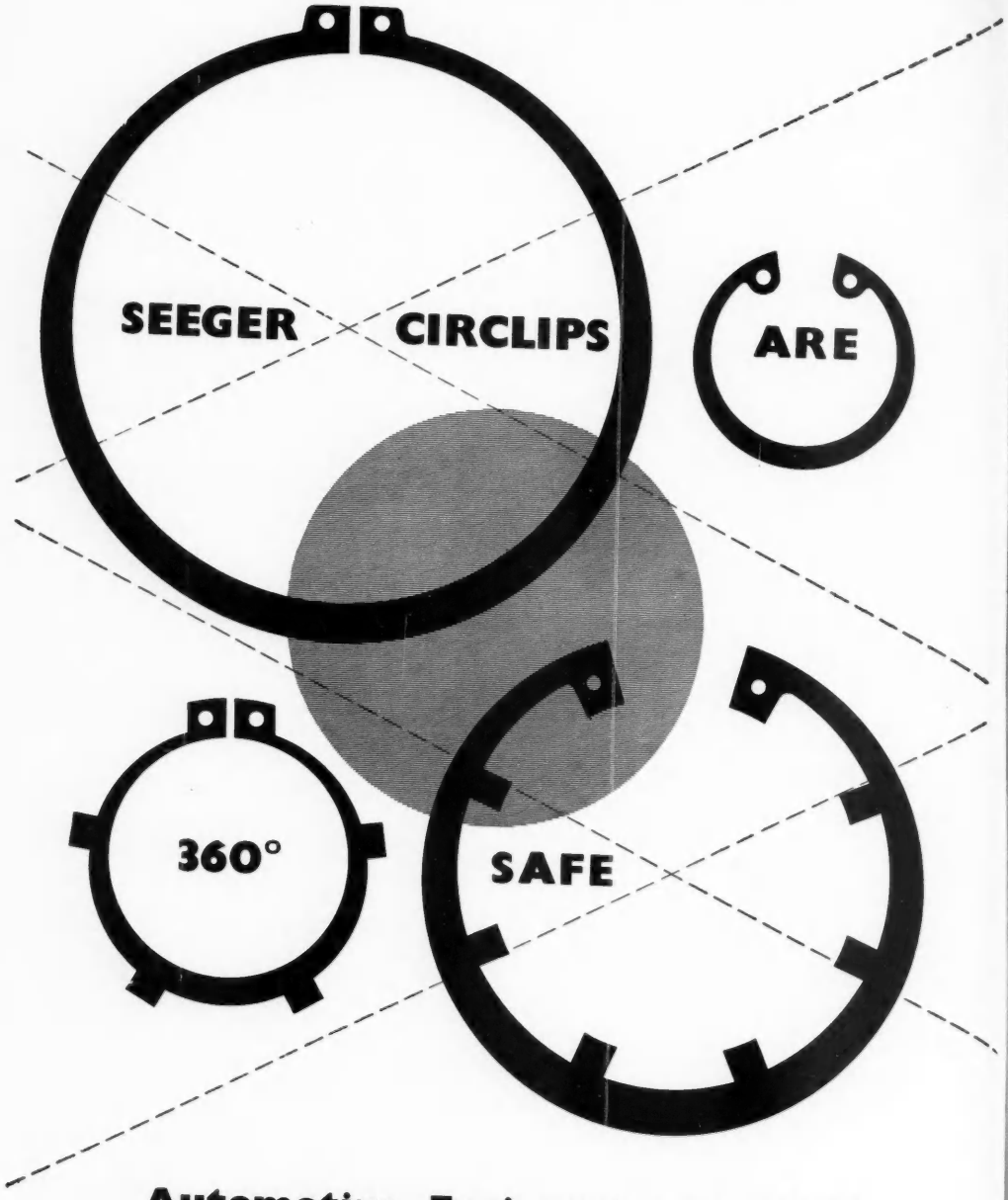
Dry-Type Flameproof Mobile Transformer for Mines

Specially designed for use in gaseous coal mines, a new 300-kVA, 3-phase 3300/565-V mobile transformer produced by the Brush Electrical Engineering Co. Ltd. is the first wholly British dry-type flameproof unit of its type. When operating at its continuous maximum rating in an ambient temperature not exceeding 25°C, the transformer requires 36 hr to attain steady temperature conditions and, under the cyclic loading conditions encountered in shift-work, overloads as high as 150% full load can be sustained for considerable periods. The maximum case temperature is below that of the conventional oil-filled transformer. Furthermore, the additional drop in temperature which takes place across the cooling fins acts as a safeguard against personnel suffering burn discomfort through accidental contact.

The transformer core, which is of interleaved construction, is built up of high-quality insulated, cold-reduced, grain-oriented steel laminations. The legs are bound with glass tape, and the yokes are rigidly supported by steel clamps bolted in position. In the winding construction, rectangular conductors of high-conductivity soft-drawn electrolytic copper, wrapped in asbestos, are used for the high- and low-voltage coils, which are also wound in square-form, thus economizing in overall dimensions. Two tappings, in addition to the normal voltage ratio, are situated at the electrical centre of the winding and are taken to a link-board via copper leads, encased in glass sleeves impregnated with silicone resins. This link-board is accessible through a bolted hand-hole cover on the side of the transformer tank.



The cylindrical transformer casing is made from structural steel plate. Careful cleaning of the casing is ensured by shot-blasting before assembly. Core clamps and all internal surfaces of the tank are painted with an anti-corrosive heat-resistant paint. The four flanged cast-iron wheels on which the transformer is mounted are arranged to suit any track gauge between 18 and 36 in. A free vertical movement of approximately 2 in. is obtainable on



Automotive Engineering Limited

One of the Sheepbridge Engineering Group

The Green, Twickenham, Middlesex

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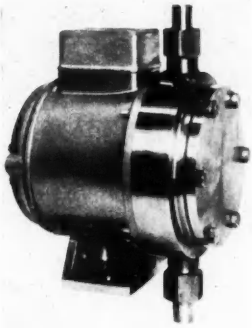
each wheel, so that any slight unevenness in the track can be negotiated without difficulty. The overall length and width of the unit are 9 ft 3 in. and 3 ft 3 in., the maximum height (with a 5-in. ground clearance) being 4 ft 2 in. These reduced dimensions, coupled with the flexible wheel arrangements provided, are exceptionally conducive to ease of manoeuvring—an essential requisite in the constricted areas in which this type of equipment is normally located.

Glandless Pumps

The latest addition to the extensive range of pumps manufactured by Sigmund Pumps Limited, of Gateshead, is their "Zero Leakage" pump, which has been specially designed for operations where it is essential that there should be no leakage whatsoever of the liquid to be pumped. The new pump has a maximum output of 8 gpm, with heads up to 60 ft, and, by virtue of its compact design, is eminently suitable for installation in confined spaces.

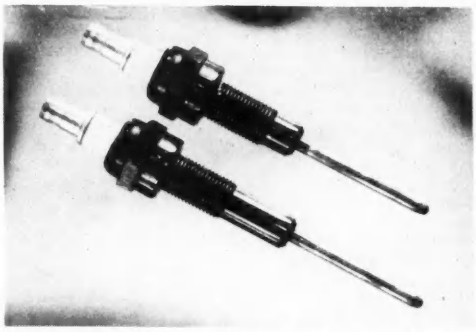


Constructed of stainless steel, the pump is of the canned-rotor type, completely eliminating the use of glands, mechanical seals, or similar sources of possible leakage. The bearings are lubricated entirely by the pumped liquid, so that no contamination by oil or grease is possible. The rotating element, mounted on a fixed stationary axle, is hydraulically and dynamically balanced to ensure smooth operation. Consequently, as there is no thrust bearing in the unit, the life of the rotating parts is greatly extended. The end-cover is easily removable to give access to the rotating element, which can be withdrawn without breaking pipeline joints and without interfering with electrical connections. The squirrel-cage rotor is entirely shrouded in stainless steel, and the standard design of totally enclosed stator is suitable for pumping temperatures up to 260°F, though special windings are available to permit pumping between sub-zero temperatures and 400°F.

Sheathed-Element Glow-Plug for Diesel Engines

An entirely new type of glow-plug for diesel engines, in which a sheathed element replaces that of the conventional exposed-coil plug, has been produced by K.L.G. Sparking Plugs Ltd., in conjunction with Metropolitan-Vickers Electrical Co., Ltd. A specific advantage of the new plug, apart from increased efficiency in general, is that, with a "working-end" diameter of only $\frac{1}{8}$ in., compared with about $\frac{3}{4}$ in. for the average conventional exposed-coil plug, the sheathed-element heater needs a correspondingly smaller entrance hole into the precombustion chamber, allowing the use of larger coolant passages around the precombustion chamber and, at the same time, reducing lost compression effect and giving noticeable improvement in power.

The main feature of the plug construction is that the



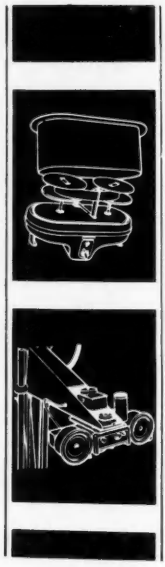
heating element is protected in an insulating material, itself shrouded in an Inconel sheath. As a result, combustion gases, which tend to deteriorate the elements of conventional exposed-coil plugs, even after they have performed their duty of assisting starting and after the current has been switched off, cannot reach the protected element wire, which can therefore be of much thinner gauge than is possible with exposed-coil plugs. The element can be designed to work at the full battery voltage, consuming proportionately less current for a given voltage, and the plugs can be wired in parallel, instead of in series. Consequently, there is no need for voltage dropping ballast resistors and, in the event of plug failure later on, the engine can still be restarted on the other plugs, so that the whole system is not rendered inoperative, as is the case with series connection. The current consumption of a 4-cylinder engine is only about 20 A, i.e., approximately half that of most open-coil plug systems.

It should be understood that the presence of the insulating medium between the heated coil and the sheath does not result in an increased warm-up time. In fact, owing to the relatively short path and the tight packing of the magnesium oxide used, the warm-up time is about 20 sec, which is quite as good as that of a conventional exposed-coil type of plug.

Equipment for Manufacturing Spirally Welded Tubes

Details of a range of machines for the production on a continuous basis of spirally welded tubes, pipes, containers, and other cylindrical bodies have been received from the concessionaires for the U.K. and the Commonwealth, Vicsteels Limited, of London, W.C.2. These machines, which are manufactured by Driam S.A., of Vaduz, Liechtenstein, have the advantage that they enable a large range of diameters to be covered by any one model of machine and that one width of strip can suffice for the manufacture of a range of tube diameters. Thus, of the seven models available, the smallest can produce tubes of from $\frac{1}{2}$ to 3 in. in diameter, using strip of from 2 to 5 in. in width, while the largest model is suitable for producing pipes of from 40 to 80 in. in diameter, using strip of from 48 to 96 in. in width. The maximum wall thickness of tubes made with the smallest model is $\frac{1}{4}$ in. and with the largest $\frac{5}{8}$ in., the respective maximum outputs being 0·5 and 15 tons per hour.

The materials normally used are hot- or cold-rolled steel strip in coils, having a tensile strength between 24 and 33 tsi, but special steels and non-ferrous metals can also be used, provided, of course, that they are weldable. The strip is unwound from the coils and is guided by side rolls onto a set of five straightening rolls, after which it passes through a pair of rolls under adjustable hydraulic pressure and then through guides to the forming tool, into which it is introduced at a predetermined angle. This angle, which is dependent on the width of the strip



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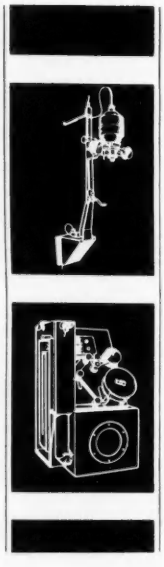

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and the required diameter of the finished tube, is smaller than the theoretical angle necessary to produce a tube which would entirely fill the semi-cylindrical forming tool. As a result, the formed strip contacts the forming tool tangentially only, reducing friction to a minimum. The formed tube is welded inside and outside and emerges continuously from the machine, passing through a guide stand onto a number of tube rests, where it is finally cut to the required length.

Optional ancillary equipment, comprising tube-cutting machines and equipment for welding one coil end to another, can also be supplied, thereby making all operations continuous. In addition, for the manufacture on site of tubes up to 30 in. in diameter, mobile installations are available.

Peak-Pressure Indicator for Diesel Engines

Registering peak and initial cylinder pressures on a dial-type gauge, the "Diesindicator", is the latest instrument in the range of diesel-engine service equipment manufactured by the Dunedin Engineering Co. Ltd., of London, W.1. The instrument provides immediate visual readings, without the need for making complicated adjustments before or during use, and is suitable for low-, medium-, and high-speed diesel engines where access to the combustion chamber is provided. Application is simple and rapid, and it can be used in either the vertical or the horizontal position.

As no piston or damper is incorporated, not only is inertia minimized, but carbon deposit is very greatly reduced, so that the instrument will continue to operate effectively over long periods without requiring dismantling and cleaning. Thus, for example, as distinct from other types of similar instruments, which normally require cleaning after only a few applications, the new indicator provides from 75 to 100 applications without sooting up, while eventual cleaning of the internal cartridge used can be effected quickly and easily.

Special materials for resisting heat, shock, and corrosion are employed, and the 2000-psi gauge, graduated in both psi and kg/cm², is housed in a steel case fitted with a special Bourdon tube. Peak and initial pressures are accurately registered on the gauge and can be held until released by the operator.

Method of Silencing Axial-Flow Blowers and Compressors

A completely new method of reducing noise from their range of single- and multi-stage axial-flow air blowers and compressors has been evolved by Plannair Limited, of Leatherhead, Surrey. This development should be of particular value in aircraft, where there is an increased emphasis on silence, and in the field of computers, where the noise level from high-output blowers often causes discomfort and even fatigue to operators.

In solving the problem of noise reduction, Plannair have concentrated on reducing the amplitude of vibrations in the range causing the greatest discomfort, i.e., between 900 and 3000 cps, and this has been achieved by packing the space confined by the exterior surface of the circular housing and end-flanges with a sound-absorbent material held in position by an outer wrapper plate, noise vibrations being intercepted and absorbed by specially located openings in the main blower housing. Tests on blowers modified in this way have shown that the reduction in noise level in the range between 900 and 3000 cps is equivalent to about 15 dB. It should also be noted that no external additions need be fitted to the equipment, the dimensions of the silenced blower being identical with those of a comparable unsilenced model, and that there is no appreciable alteration in performance.

Transistorized Desk-Size Digital Computer

Weighing about 550 lb and measuring approximately $7 \times 3\frac{1}{2} \times 4$ ft high, including a standard "office" desk, the "Sirius" transistorized electronic digital computer, manufactured by Ferranti Ltd., of Hollinwood, Manchester, is believed to be the smallest and most economically priced computer yet produced in Europe. The new computer, which is powered directly from standard mains supplies, is basically intended to provide a small and relatively inexpensive machine for those sections of industry, commerce, and research which need a computer but which do not have the requisite volume of work to keep a large machine economically occupied. Its chief application is expected to be in statistical analysis, though it can also perform many other types of jobs. In addition, it should be of great use in technical colleges for general educational and instructional purposes, and should also provide a valuable ancillary machine for a large computing installation, enabling additional experimentation to be computed without interrupting the main machine.

The computer, which was shown for the first time at the recent International Transistor Exhibition in London, is essentially constructed of neuron packages and magnetostriction delay lines, and is fully transistorized. The machine works in decimals, each decimal digit being represented by four binary digits. Checking is effected inside the machine by automatic detection of forbidden combinations. Input and output is on 5-hole paper tapes, and a set of 100 buttons, similar to a desk calculator, can be used to operate the machine or to put information directly into the main store. The instruction being obeyed is displayed on a set of forty lamps, a second display being used to monitor any accumulator. The speed of the input system is 300 characters per second with the ability to stop on any one character, while the speed of the output system is 33 characters per second for punching, or 10 characters per second for printing tape.

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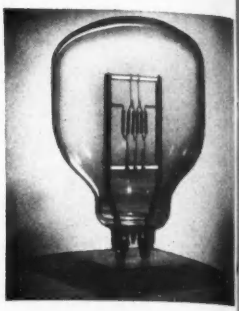

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ADDITIONAL ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

The Effects of Residual Stress on Brittle Fracture.

By H. KIHARA and K. MASUBUCHI. (From *The Welding Journal, U.S.A.*, Vol. 38, No. 4, April 1959, pp. 159*s*–168*s*, 5 illustrations)

IT is a particular nature of brittle fracture that the actual damage usually occurs at a considerably low stress. The evidence obtained from actual failures in ships and other welded structures has indicated that, in numerous cases, these failures occur at the stress far below the yield stress of the material, i.e., 7 to 10 kg/mm². On the other hand, it has been noticed that the nominal fracture stress of a notched specimen is as high as the yield stress, even in specimens containing very sharp cracks. Consequently, it is very important to investigate the mechanism of how brittle fracture occurs at such a low stress level in welded structures. In addition, it is important to clarify the effects of residual stress on the strength of welded structures, as high residual stress is produced by welding.

As described in this paper, an experimental investigation has been carried out in Japan by the authors into the effects of residual welding stress on brittle fracture. For this purpose, the specimens, having a sharp transverse notch in the region of high-tensile residual stress, were pulled by the testing machine under various temperatures. It was found that residual welding stresses having no effect on the ductile fracture of welded structure may play an essential role in the case of brittle fracture. The complete fracture of a welded joint may be produced merely by applying low stress in a static manner under such unfavourable conditions as the use of materials of low notch toughness and the existence of sharp notch and high-tensile residual stresses.

The effect of preloading at high temperature on the behaviour of a joint was also investigated, and it was found that preloading produces favourable effects on the fracture strength at low temperature. In addition, the authors' personal opinions on the application of stress-relieving heat treatment and non-destructive testing for the prevention of brittle fracture are presented.

The Selection of Corrosion and Scale Inhibitors for Cooling Water.

By H. SHIELDS, L. V. SORG, and R. L. STUTZ. From *Corrosion, U.S.A.*, Vol. 15, No. 5, May 1959, pp.29–32, 7 illustrations)

As described in this paper, a number of corrosion inhibitors for refinery cooling water have been subjected to four phases of testing, i.e., bench tests, pilot-plant tests, tests with a small-size commercial cooling tower, and full-scale plant tests. Two types of test specimen were used, i.e., a low-carbon steel (representative of general piping and the tubing in some coolers) and Admiralty brass (representative of the tubing in about 80% of the coolers).

Only three of the fifty inhibitors investigated over the past nine years were given full-scale tests. Of these, it was found that phosphates, while exhibiting fair corrosion protection, have the disadvantage of depositing scale, even at low pH values. Only the chromate type of inhibitor proved satisfactory in all phases of testing. Organic chromates were found to be particularly effective for the river water used in the refinery concerned in the tests. However, two weaknesses still persist, i.e., (1) organic chromates are degraded and rendered ineffective if mercaptan-containing oil leaks into the water-circulation system, as the mercaptans react with the chromium to precipitate chromium sulphide, so that excess amounts of costly organic chromate must be added to compensate for that de-activated, and (2) the organic portion of the inhibitor, when disintegrated, is insoluble in water and collects as a gelatinous sludge on metal surfaces. The search therefore continues for a corrosion and scale inhibitor that is effective in all circumstances.

The Transient Behaviour of a Three-Phase Induction Motor Studied with an Analogue Computer.

By J. F. BLOM. (From *De Ingenieur, Holland*, Vol. 71, No. 19, May 8, 1959, pp. Ch. 1–Ch. 7, 8 illustrations)

THE electromechanical quantities which are characteristic of the behaviour of an induction motor can be classified into two basic categories, i.e., (1) torque, speed, current, and other quantities of interest, when there is such a load that no acceleration of the rotor occurs, and (2) the transient, e.g., the instantaneous values of the torque, speed, and current as functions of time, when there is an acceleration of the rotor.

Within the second category a further two divisions can be made, the first being that of slow incremental variation in speed, where the torque equation can be ignored to a first approximation. For this case, linear differential equations describe the transient behaviour of current, and the solutions of these equations may be given in terms of elementary functions. The second subdivision, which is the case considered in this paper, is that of a high derivative of velocity, where the torque equation must be taken into account. This case generally results in a set of simultaneous non-linear differential equations which may be solved by numerical methods. However, the large number of parameters associated with the problems which arise in this category make it extremely difficult to obtain an adequate survey using numerical techniques.

The development of the electronic analogue computer has provided a convenient tool for investigating the problem of electromechanical transients in rotating machines. The analogue computer can easily be set up to solve the equations governing the behaviour of an electric motor, and the parameters of interest can easily be varied in order to investigate a great number of cases. In addition, the effects of backlash, coulomb friction, and many other arbitrary non-linear effects can readily be examined.

In this paper, some results of the transient behaviour of a three-phase induction motor are given, three simultaneous non-linear equations for finding the torque, velocity, and current being solved by the aid of an analogue computer. Furthermore, the equations governing the transient behaviour of an induction motor are derived, and a block diagram of an analogue computer set-up for transient studies of a three-phase induction motor is presented.

High-Precision Non-Destructive Thickness Measurements of Organic Coatings.

By E. P. BRIGHTWELL. (From *ASTM Bulletin, U.S.A.*, No. 237, April 1959, pp. 67–69, 3 illustrations)

FUNDAMENTAL research on the properties and behaviour of organic coatings frequently uses thickness or changes in thickness as one of the important parameters. Such research also frequently requires sequential thickness measurements to be made on a given spot during the course of an experiment. Non-destructive methods based on electromagnetic induction instruments have long been available, but these are limited to magnetic substrates and often lack the required precision. An accurate but semi-

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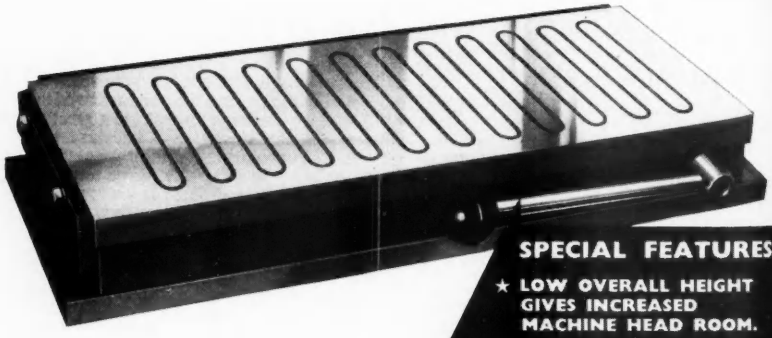

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destructive optical method is also available for measuring film thickness. Non-destructive measurements of very thin clear films have also been made by using interference phenomena which occur when a thin film is exposed to visible light. However, the use of visible light restricts this method to very thin clear films (less than 0·1 mil thick).

In this paper, a method based on infra-red interferometry is described. The method has an average standard deviation of 0·008 mil for coatings 0·1 to 3 mils thick. It is applicable to pigmented coatings attached to any reasonably smooth metal substrate and to clear films over silicon or graphite. It is rapid, non-destructive, and can be carried out with any infra-red spectrometer equipped for reflectance measurements.

This method has proved to be very satisfactory for measuring loss of film thickness due to degradation. In addition, it has detected large differences between different polymeric systems, and has also demonstrated the protection afforded by pigmentation of the same systems.

Vibration of Cascade Blades Treated by Actuator-Disc Methods.

By D. S. WHITEHEAD. (From an advance copy of a paper received from *The Institution of Mechanical Engineers, London*, May 1959, 11 pages, 6 illustrations)

In this paper, the stability of the two-dimensional flow of an incompressible, inviscid fluid through a cascade of turbine or compressor blades, which are free to vibrate, is considered, and attempts are made to find the conditions under which a small disturbance of the flow, in which velocities vary sinusoidally with time, can exist. Consequently, on one side of this neutrally stable condition there will be stable flow and on the other side unstable flow. The theoretical methods described of calculating the aerodynamic forces on these vibrating blades are subject to two fundamental limitations, i.e., (1) the time taken for the fluid to flow through the cascade must be small, compared with the time of one oscillation of the flow, and (2) the adjacent blades must vibrate nearly in phase.

The conclusions derived from this investigation may be summarized as follows:—

(1) Bending vibration of unstalled blades with small mean deflection is always damped.

(2) A criterion for bending flutter of unstalled blades with large mean deflection has been derived, and is qualitatively supported by experiments carried out by previous investigators.

(3) A condition of instability of the flow through stalled cascades of fixed blades has also been derived, and has been found to be in agreement with the results of other investigators.

(4) A criterion of the bending flutter of stalled blades has been established and it is shown that this limit is reached before the instability limit referred to in (3) above.

(5) It has been found that, except for a particular case of zero-stagger cascades, flutter of unstalled blades in torsion will always occur. For this case, however, the first fundamental assumption referred to above is unlikely to be true, and more detailed examination of this case has been proposed.

The Influence of Different factors on Strain-Ageing Embrittlement in Mild Steels.

By A. JOSEFSSON. (From *Jernkontorets Annaler, Sweden*, Vol. 143, No. 3, 1959, pp. 121–150, 11 illustrations)

This paper describes a series of investigations carried out in order to establish the relation between the amount of strain and the Charpy impact transition temperature after strain-ageing a number of mild carbon rimming, semi-killed and fully killed steels, containing 0·03 to 0·19% carbon and 0·19 to 1·4% manganese. Deformation was obtained by tension, by compression, and by drawing through a die. In particular, the shift in transition temperature corresponding to an increase in natural strain ε from 0·1 to 0·2 was determined. This shift was found to vary considerably and to have any value between 0 and 100°C and higher, depending on the method of deformation, type of steel, and method of heat treatment. For one and the same material, compression generally gave a higher degree of embrittlement (raise in transition temperature) than tension or drawing. The difference was greatest for steels with an inhomogeneous structure. On the other hand, a decrease in transition temperature was found to appear in some cases, when the value of ε was considerably higher than 0·2.

Additional experiments, made in an attempt to find an explanation for the higher degree of embrittlement after compression, did not give conclusive results. However, two factors, brought out by these experiments, which may have a bearing on the problem, may be summed up as follows:—

(1) Tensile tests on previously compressed specimens showed that steels highly embrittled by compression have no marked yield point, even after ageing, while steels only slightly embrittled by compression have a yield point.

(2) Microhardness measurements showed that spread in hardness between adjacent areas in the structure is increased by deformation.

As a tentative explanation of the phenomena observed, it is assumed in this paper that strain-ageing embrittlement is mainly caused by " soft zones " in the structure, in which critical stress for inducing plastic deformation is lower than in the adjacent parts. Plastic deformation may produce or intensify such differences in hardness, while impact stressing causes a limited plastic deformation in the soft zones, which then act as internal notches. Ageing may also increase the difference in critical stress for plastic deformation between the soft zones and their environments, and the development of such zones may be promoted by structural inhomogeneities.

Chemically Frozen Boundary Layers with Catalytic Surface Reaction.

By D. E. ROSNER. (From *Journal of the Aero/Space Sciences, U.S.A.*, Vol. 26, May 1959, pp. 281–286, 2 illustrations)

When a fluid boundary layer containing a single reactant develops along a solid surface which acts chemically as a sink distribution for this species, its steady-state concentration along the surface, and hence the reaction rate distribution, depend on the true surface chemical kinetics and a combination of convective and diffusive mass transport through the fluid. In this paper, a simple approximate method is presented for studying this streamwise distribution of reaction rate in terms of shear and temperature distributions along the surface. This method is based on a treatment of the concentration integral equation which initially parallels Liepmann's recent treatment* of the energy integral equation but which ultimately leads to a differential equation for the concentration distribution of reactant along the surface.

This approach to " mass-transfer " problems, which is intended to bring out clearly the role of the governing catalytic parameter, as well as several interesting properties of solutions, is then compared with other techniques. The reactant concentration is considered to be so small that constant diffusion coefficient, viscosity coefficient, and Prandtl number for diffusion can be assumed, and the fluid is taken to be incompressible, with a catalysed reaction taking place only at the wall. Thus, the hydrodynamic field is unaltered by the surface reaction, and only the effect of small surface temperature differences on the kinetics of the wall reaction, i.e., the effective " sink " strength, are taken into account. In addition, extension to the case of several reactants is discussed, and an interpretation of the governing catalytic parameter as a ratio of characteristics times is given.

* *J. Fluid Mech.*, Vol. 3, Part 4, January 1958, pp. 357-360.

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New Materials, Processes, and Equipment

MINERAL-INSULATED THERMOCOUPLES

British Insulated Callender's Cables Limited, of London, W.C.1, who have for some time been manufacturing mineral-insulated cables, are now applying the principle of mineral insulation to thermocouple production, the thermocouples being welded together at the hot junction, embedded in an insulant of highly compressed magnesium oxide, and completely encased in a seamless, circular sheath of stainless steel. The sheath is welded over to form a hermetic seal completely insulated from the conductors, but this procedure does not increase the overall diameter of the cable or complicate installation, inasmuch as thermocouples with an overall diameter of 0·060 in. are being produced in this way. In fact, standard overall diameters are at present 0·060 and 0·122 in., though intermediate sizes can also be supplied, if required. A seal is fitted at the cold end to prevent the insulant from absorbing moisture. The seal body is threaded to facilitate entry into junction-boxes and instrument casings, where it can be held in place by locknuts. The cold-end assembly will operate at temperatures up to 150°C.

These thermocouples give a rapid thermal response, since the small volume and high density of the insulant offer excellent conductivity.

AUTOMATIC TRANSACTION-RECORDING AND DATA-COMMUNICATIONS SYSTEM

Claimed to be the first successful development of completely automatic transaction-recording and data-communications equipment, the " Transacter " system, announced by the Stromberg Time Corporation, a subsidiary of the General Time Corporation, of Thomaston, Conn., make it possible to collect information at remote sources and to feed it instantaneously to central electronic " brains " or to data-processing centres. Generally speaking, the system is expected to find a wide application in all mass-production industries, especially the aviation and automative industries, and also in the field of home-appliance manufacture.

Designed to be completely compatible with other business-machine and data-processing equipment now widely used in industry, the Transacter system eliminates the need for paper work and clerical operations between the source of a transaction and the data-processing centre. In any given installation, Transacters (one of which is shown in the right foreground of the illustration) are located at any required number of remote transaction stations, and each Transacter accepts punched cards or tags containing certain prerecorded information. In addition to the prerecorded data, the Transacter identifies the operator and location, together with the specific item or machine operation covered by its report. All pertinent variable data, e.g., the number of pieces produced or received, is set on a dial by the operator. Rounding out each transmission is a transaction code designated by a selector on the panel of the instrument.

All information is transmitted instantaneously to a compiler or receiving-recording station, located in the central processing office, which may be as much as three miles distant. In the compiler (middle background of illustration), such information as shift, date, and time, end-of-message code, and instructions to subsequent processing equipment are added to each message received from each Transacter on the system. Completed messages are recorded by the compiler in programmed sequence on 5-, 6-, 7-, or 8-channel tape at a speed of 60 characters per second. The output tape is suitable for immediate use and can be fed directly into communications systems, automatic typewriters, tape-to-card converters, or electronic data-processing equipment. Self-checking mechanisms throughout the system verify the accuracy of output messages.

STABILIZED POWER-SUPPLY UNIT

Providing a constant-voltage source of 600 V positive and two stabilized negative 150-V d.c. supplies, one of which is a variable line with a high-impedance source, the new type L.101 stabilized power-supply unit announced by Advance Components Limited, of Hainault, Ilford, Essex, has the unique feature that two stabilized 6·3-V a.c. supplies are also provided. As a result, valve heaters can be fed with a constant voltage to maintain valve characteristics stable and to eliminate errors arising from filament-supply variations from fluctuating mains supply.

The stabilized negative line with a high-impedance source is variable between 0 and 150 V and can be used as a grid-bias supply or for use in circuits drawing a small current load of not more than 5 mA. An unstabilized line of from 100 to 800 V is also provided for general use. The two positive lines have a maximum total load rating of 300 mA, and the positive 600-V and negative 150-V d.c. outputs can be used in series to provide a total of 750 V d.c. stabilized output, with a maximum rating of 30 mA. Voltage variation on the positive 600-V and negative 150-V lines is better than 0·03% of output for a 10% variation in input voltage, while the output variation from the two 6·3-V a.c. lines is less than 0·02 V for the same condition.

Adequate metering facilities are provided, the voltmeter being calibrated from 0 to 250 V and 0 to 1000 V, and the ammeter from 0 to 50 mA and 0 to 500 mA. Other facilities include control of the high-tension stabilized d.c. line, enabling the output to be set to any desired level up to 600 V, together with a source resistance control over the range between 0 and 40 ohms. Hum can be superimposed on the stabilized d.c. high-tension line and can be varied between 0 and 6 V r.m.s. to provide a sine wave of good quality at the mains input frequency. Ripple content is less than 3 mV r.m.s. on all stabilized outputs at 150 V and below, and less than 0·002% r.m.s. at voltages above 150 V. On the unstabilized 800-V d.c. line, ripple content is about 3 V r.m.s. with a 300-mA

dependability

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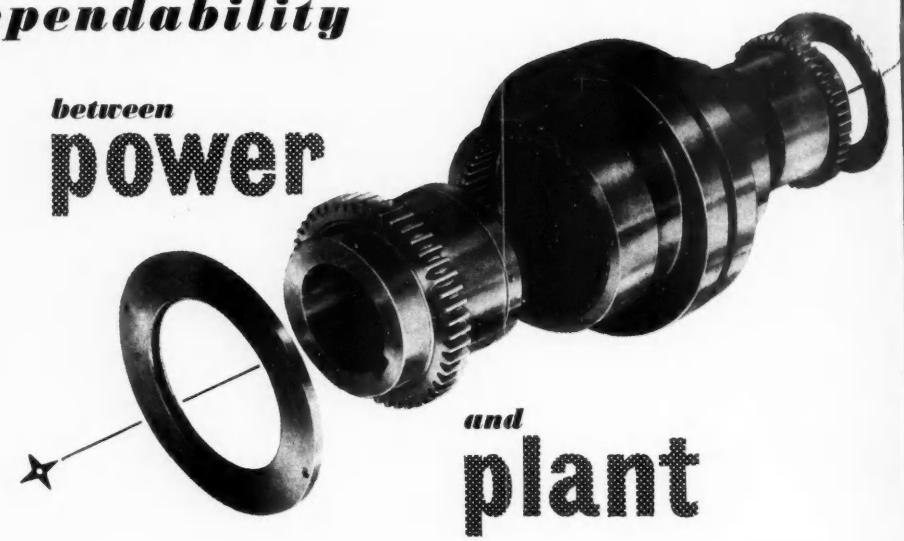
power



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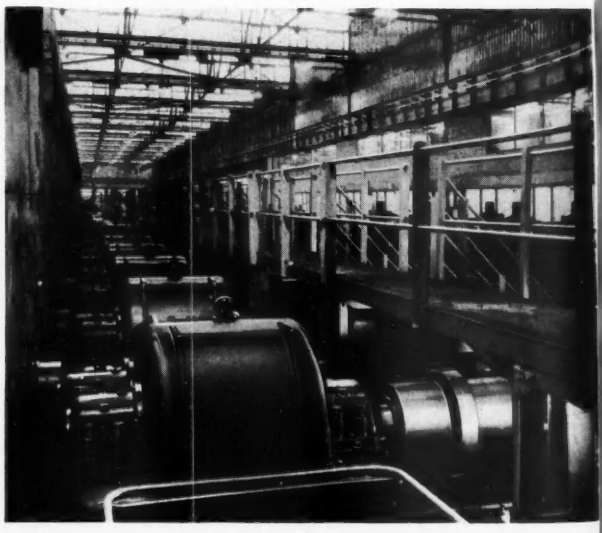
"Brightside 17—Stand 11" Continuous Bar Mill driven through David Brown Helical Gear Units and Gear-type Couplings. Photograph by courtesy of The Park Gate Iron & Steel Company Limited, Rotherham.



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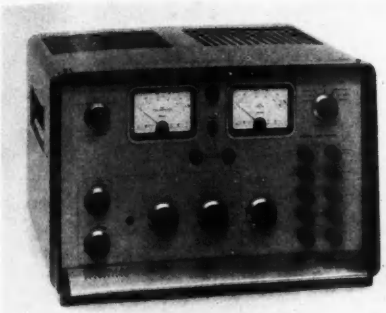
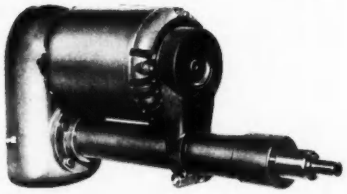


load. As a result, the instrument has many applications in systems requiring a stabilized high-power, high-voltage supply of low impedance and small ripple content.

ELECTRO-MECHANICAL THRUST UNITS

A standard range of self-contained electro-mechanical thrust units, designated " Autoram ", is now being produced by the Gear Division of George Angus & Co. Ltd., of Newcastle-upon-Tyne. These units are offered as alternatives to solenoids, and to hydraulic, compressed-air, and vacuum-operated cylinders, and have the advantage that they can be operated directly from standard a.c. mains supply lines, using standard types of switchgear and eliminating the need for special power sources such as air compressors and hydraulic pumps.



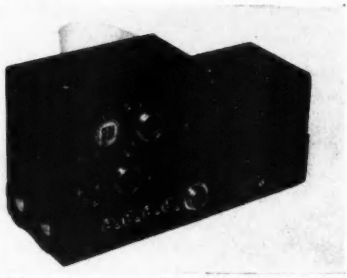
Each unit incorporates an electric motor, totally enclosed reduction gearing, and a ram which is extended or retracted by means of a screwed shaft-and-nut arrangement. A special limit-switch is normally fitted for the purpose of controlling the stroke, and this can readily be adjusted to provide any stroke length in the range of the unit. Various sizes of foot-, flange-, or trunnion-mounting unit are available, suitable for thrust loads up to 5000 lb and with maximum stroke lengths in accordance with users' requirements.

MINIATURE INSTANTANEOUS-TRACE RECORDER

Measuring only $4\frac{1}{4} \times 5\frac{3}{4} \times 11\frac{1}{4}$ in. approximately, and weighing less than 10 lb, the new entirely self-contained SFIM U.V. recorder, manufactured in England by SFIM (Great Britain) Limited, of Slough, Bucks, is believed to be the smallest and most versatile instrument of its kind in the world. A special feature is that it provides virtually instantaneous traces without any need for the processing of the photographic paper normally used in this type of recording, this being achieved by the use of special recording paper and a high-pressure mercury-vapour lamp.

The instrument, which is specially suitable for road, rail, and marine transport applications, operates from an external power source of 50 V d.c., and makes it possible to record up to six continuously varying and two discontinuous parameters against an accurate 1-sec time base. Up to 20 ft of 60-mm paper can be accommodated in the recorder itself but, for longer durations, an external clip-on cassette, with a capacity of 100 ft of paper, is available. At the moment, three types of recorder can be supplied, these differing only in the speed of the paper, i.e., 1 and 5 mm/sec, 5 and 25 mm/sec, or 100 mm/sec.

The recording principle is conventional in that each of the recording elements is provided with its own mirror or series of mirrors, displaced under the influence of the quantity being measured. The image of the light source is reflected by the mirror in such a way that the light spot traverses the length of the recording aperture for a full-scale range of the element. In this way, the traces can cross each other, achieving full deflection across the recording paper.

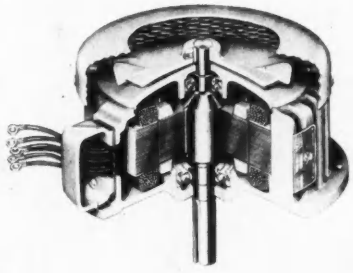


In addition to a range of oscillographs for use with the recorder, a variety of elements is available for different measurements. For example, direct measurements of differential or absolute pressure can be made with special elements which do not require any electrical connections. Similarly, direct-recording elements, also requiring no electrical connections, are available for the simultaneous measurement of acceleration in all three planes. Another useful and versatile element is a ratiometer for measuring the ratio between two currents applied to its two sets of coils. This element can record phenomena occurring up to a frequency of about 25 cps and its correct operation is virtually independent of voltage variations. Special versions have been developed for measuring frequency, current, and voltage.

" PANCAKE " ELECTRIC MOTORS

Basically intended for use in machine tools, roof ventilating vans, and other applications where space may be at a premium, the new range of " pancake " electric motors recently developed by The Louis Allis Co., of Milwaukee, Wisconsin, reduces overall motor length by as much as 60%, compared with conventional motors of the same rating. These motors, which are available in ratings of from 1 to 15 hp at 1800, 1200, and 900 rpm, are of conventional radial air-gap design, but achieve their markedly reduced length, without any sacrifice of performance, by means of formed end-coils and a one-piece housing bearing bracket.

For normal operating conditions, the motors are built in an open drip-proof enclosure, but in cases where operation in the presence of dirt, corrosives, or other



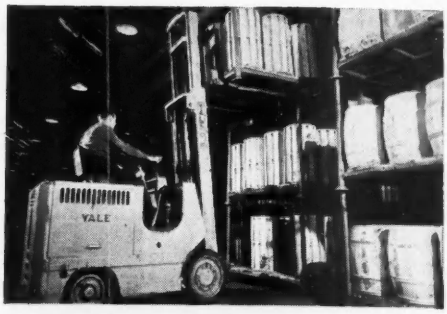
CUTTING COSTS IN INDUSTRY

Vital storage space saved, production delays ended, with versatile Yale trucks

IN THE DISTRIBUTIVE TRADES . .

Warehouse capacity increased by 15%, labour force reduced by 18% and released for more productive work. These are among the striking economies achieved by Galbraith's chain grocery stores since installing a fleet of 31 Yale trucks of various types. Over 900 different 'lines' are supplied to 200 shops from Galbraith's Scottish warehouse. The Series 51 truck, shown here stacking palletised barrels of butter, has helped to speed handling and cut storage costs by working in narrow aisles and stacking 14 feet high. Quantity of goods handled in an hour has risen by over 30%.

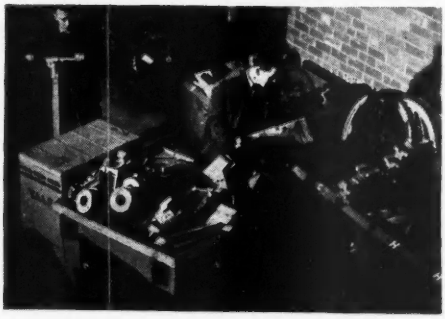
Yale Series 51 electric trucks are available in capacities from 3,000 lbs. to 10,000 lbs.

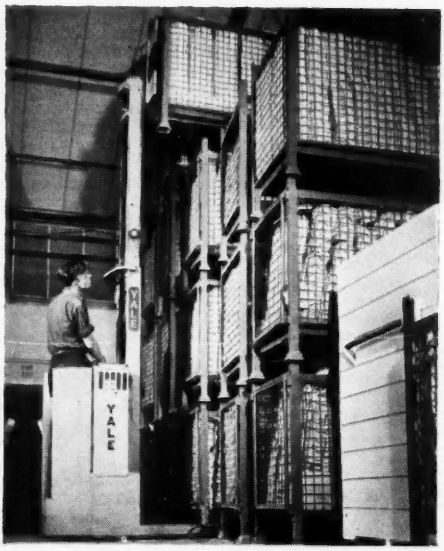


IN FOUNDRIES . . .

Production delays are minimised by Yale trucks in the Leeds foundry of Catton & Company Limited. In Fettling Shop and Despatch Department, movement by electric platform Worksaver saves time and ensures most productive use of labour. The truck seen here with castings being segregated in the Despatch Department is so simple to use that no special truck operator is required.

Yale Worksavers are available in Platform or Pallet models (2 or 3 tons) ; Fork Lift (1,500, 2,000, 2,500, 3,000 lbs.); Tractor (700 lbs. draw bar pull).





...IN PRINTING Storage of a weekly intake of 75 tons of paper and board is no problem at Taylowe Ltd. Three Yale trucks speed handling and ensure maximum use of storage space in warehouse and production areas. This Yale Warehouser, working in aisles only 6 feet wide, and stacking pallets 13' 6" high, helps maintain strict inventory control over all stocks.

Yale Warehousers are available in Platform models (2 tons) ; Fork Lift models (2,000 and 3,000 lbs.).

The Yale range includes power trucks for every need up to 200,000 lbs; Hand Trucks for loads up to 12,000 lbs; Hoists for lifting up to 40 tons (trolleys for all models); Pul-Lifts (from ¾ to 15 tons).

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contaminants is envisaged, an enclosed construction is used. For ratings up to 1½ hp, no ventilating fan is used, the excellent heat-dissipating qualities of the ribbed cast-iron housing permitting operation with only a conservative temperature rise. In the case of ratings of 2 hp and higher, a ventilating fan is incorporated and serves to cool the motor adequately, but still, however, maintaining an exceptionally short overall length.

CO-ORDINATE DRILLING AND BORING MACHINE

The latest addition to the range of machines produced by Grimston Electric Tools Ltd., of Croydon, Surrey, is their Series I co-ordinate drilling and boring machine, which is capable of use in a wide range of applications, including small batch-production runs, eliminating expensive jigs, drill spottings, boring, and similar operations. To enhance the usefulness of the machine, a selection of spindle adaptors, suitable for end-mills and other types of milling cutters, will soon be available.

The main drilling head, with a drilling capacity up to 1¼ in. in mild steel, is provided with eight spindle speeds, ranging from 90 to 1460 rpm, and four geared power feeds, from 0·0035 to 0·0080 in. per revolution of the spindle. The unit includes a depth scale, an automatic trip, and a spring return to the spindle. The head also incorporates a built-in electric motor, controlled by a push-button starter giving overload protection.

Movement of the compound table, which has a working area of 32 × 12 in., is manually controlled, and recirculating ball leadscrews are employed in both directions. Longitudinal movement is 20 in., and cross movement 12 in., suitable means of locking the table in position being provided. The handwheels controlling table movements have adjustable calibrated rings with 0·001-in. divisions, and equipment for the table includes two dial indicators reading to 0·0005 in., trays for gauge-blocks, and built-in rules with adjustable pointers.

BORING MACHINE FOR COUPLING FLANGES

The latest addition to the range of fine-boring equipment manufactured by the Buma Engineering Co. Limited, of Newcastle-upon-Tyne, is a machine for boring the holes in coupling flanges, particularly on turbine shafts, where space restrictions oblige the use of a

machine of minimum length. The machine is very easily set in relation to the hole to be bored, and several holes can be produced without any need for turning and coupling shafts.

The boring bar runs in precision needle roller bearings which are carried in steady-brackets located on each side of the coupling flange. A cross-bracket casting, which can be adjusted vertically, is carried by two clamping units incorporating hardened steel rollers for sliding the machine and locating it on the periphery of the coupling flange. This cross-bracket is bored to take two ground-steel bars, which lie parallel to the axis of the coupling shaft and from which the two steady-brackets are suspended. One of these steady-brackets incorporates a gearbox, from which the boring bar is driven through Vee-belts and pulleys. The drive to the gearbox is from a separate power unit via a heavy-duty flexible shaft. The gearbox also carries a feed mechanism, which, through a bracket sliding on the two horizontal bars, imparts a feed to the boring bar. The feed is engaged merely by locking the feed screws with a thumbscrew on the feed bracket.

Setting the cutter to size is achieved by using a special direct-reading micrometer which is quickly clamped in position by the boring bar by means of a snap-over type of spring. The micrometer is calibrated from 1·5 to 3·5 in., but other calibrations are available. The cutters used are of tungsten carbide, and these can be sharpened, using the special jigs supplied, on a metal-bonded diamond wheel attached to the pulleys of the separate power unit.

Improved Hot-Gas Engine, using a Rhombic Drive Mechanism

(*Concluded from page 251*)

All the above values were obtained with the nominal heater and cooler temperatures of 700°C and 15°C mentioned earlier. Tests were also conducted to ascertain the effects of changes in these temperatures on power output and efficiency, and the results are shown in Fig. 8 for an engine speed of 1500 rpm and a p_{max} value of 140 kg/cm².

Finally, Fig. 9a shows the heat balance of the engine as a function of maximum mean effective pressure p_e at a speed n of 1500 rpm, while Fig. 9b shows the heat balance as a function of engine speed n at a p_{max} value of 140 kg/cm². The narrowness of the bands representing flue losses establishes the effectiveness of the air preheater, the burner having an efficiency of more than 90% over a large range of values of n and p_e. Chief among what are called "other losses" are those due to mechanical friction, though losses due to incomplete fuel combustion may also be included. It is, of course, unreasonable to expect these losses to be specified with any great accuracy but, from the good reproducibility of the results obtained, it is reasonable to conclude that the mechanical efficiency of this rhombic-drive engine is high.

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for heat, abrasion, corrosion and machining problems

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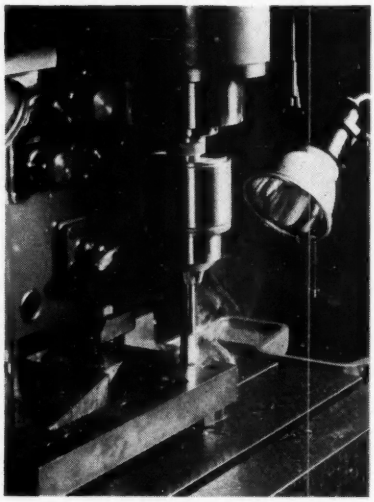

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WRITE FOR PUBLICATION B 19.
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This useful tool is going from strength to strength. It is standard equipment in many plants both in this country and abroad, for broken tap and hard screw removal, production drilling after hardening, manganese steel drilling and many other problem operations.
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NEWS OF THE MONTH

PERSONAL

Air-Marshal Sir Richard Atcherley, K.B.E., C.B., A.F.C. and Bar, has joined the board of Folland Aircraft Limited as sales director.

The Earl of Halsbury, F.R.I.C., F.Inst.P., has been appointed chairman of Lancashire Dynamo Electronic Products Limited.

Mr. W. P. Warren, B.Sc., M.I.E.E., has joined the Powell Duffryn Group of Companies and has been appointed sales director of their subsidiary company, the Cambrian Wagon and Engineering Company Limited, of Cardiff.

Mr. J. H. Dolby has been appointed secretary of the Villiers Engineering Company Limited, of Wolverhampton.

Mr. R. G. Orr, M.C., M.Inst.W., has been appointed managing director of T. C. Jones & Co. Ltd., a member of The George Cohen 600 Group.

Mr. A. A. Simons, B.Sc., has taken over the responsibility for the production and sales of all products of Colloidal Graphite Ltd., of Bernard Lane, Sheffield 2.

Mr. R. G. C. Stephenson, managing director of Indian Oxygen Ltd., has been appointed managing director, and **Mr. R. C. Booth** assistant managing director of The Commonwealth Industrial Gases Ltd., of Australia.

Mr. J. Busfield, A.C.A., secretary and chief accountant for Crofts Engineers (Holdings) Limited and Crofts (Engineers) Limited, has been appointed a director of these companies, as well as of J. Parkinson & Son (Shipley) Limited. **Mr. M. T. J. Goff,** joint managing director of Crofts (Engineers) Limited, and a director of Crofts Engineers (Holdings) Limited, has also been appointed to the board of J. Parkinson & Son (Shipley) Limited.

Mr. W. Barr, O.B.E., has been elected president of The Iron and Steel Institute. **Mr. A. H. Ingen-Housz,** past president, has been awarded the Diploma of Honorary Membership, and **Professor Count Bo Kalling** (Sweden) has been awarded the Bessemer Gold Medal, in recognition of his contributions to the physical chemistry of steelmaking. The Sir Robert Hadfield medal was presented to **Mr. A. Jackson** (United Steel Companies Limited) for his contributions to metallurgy, metallurgical education, and the development of the Ajax oxygen steelmaking process.

Following recent changes, the board of Borg Warner Limited now consists of **Mr. R. S. Ingersoll,** chairman, **Mr. H. P. Troendly,** deputy chairman and managing director, and **Mr. R. J. Breyfogle,** director. The board of Hartcliffe Chains Limited consists of **Mr. H. P. Troendly,** chairman, and **Mr. W. Harney,** managing director.

Mr. H. E. Dixon, M.Sc., F.I.M., has been appointed head of research and development of the Research Laboratories of Atomic Power Constructions Limited.

Mr. W. McLeod has been appointed assistant managing director of Saturn Industrial Gases and of its subsidiary, H. G. Sanders and Son. **Mr. E. W. Young,** secretary of Saturn Industrial Gases, has been appointed to the board of both companies.

Mr. A. J. Peech has been appointed deputy chairman of the United Steel Companies Limited.

V. L. Churchill and Co. announce that **Mr. S. H. Fletcher,** general manager, has been appointed to the board of the company.

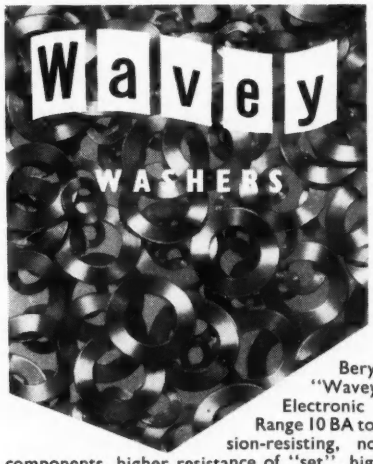
At the annual general meeting of the Electrical Development Association, **Sir Josiah Eccles, C.B.E., M.M., D.Sc., M.Inst.C.E., M.I.Mech.E., M.I.E.E.,** deputy chairman of the Electricity Council, has been appointed president of the association for the year 1959/60. **Mr. A. W. Ferguson, M.C., C.A.,** and **Mr. J. Mould, O.B.E., A.M.I.E.E.,** have been appointed vice-presidents for the term 1959–1962. At the first meeting of the association's newly constituted council, **Mr. T. E Daniel, M.Eng., M.I.E.E., A.M.I.Mech.E.,** has been elected chairman for the year 1959/60, and **Mr. D. B. Irving, B.Sc.(Eng.), M.I.E.E.,** has been elected vice-chairman.

Mr. F. H. Towler has relinquished his position of managing director of Towler Brothers (Patents) Limited, while remaining vice-chairman of the company. He will be succeeded as managing director by **Mr. E. Jones.**

Mr. D. M. Hughes has been appointed sales manager of James Gordon Valves Limited, of Rochester, Kent, a member of the Elliott-Automation group. **Mr. R. S. Hewitt** has joined the board of Elliott Brothers (London) Limited.

Mr. A. H. Hird, A.C.G.I., B.Sc., M.I.Mech.E., has been appointed to the board of the English Steel Corporation Ltd.

The Marconi International Marine Company announce that they have appointed **Mr. E. Davis** as marine superintendent.



Beryllium Copper "Wavey" Washers. For Electronic Components. Range 10 BA to ⅜" BSF. Corrosion-resisting, non-damaging to components, higher resistance of "set", higher recovery of load, permanent spring action. They are fabricated from Beryllium copper, heat treated to VPN. 350 minimum, Electro Plated to DTD.924, Cadmium Plated to DTD.904 and Passivated to DTD.923. Also supplied Silver Plated, or Self Colour or to customer's specification. Samples and price lists on request.

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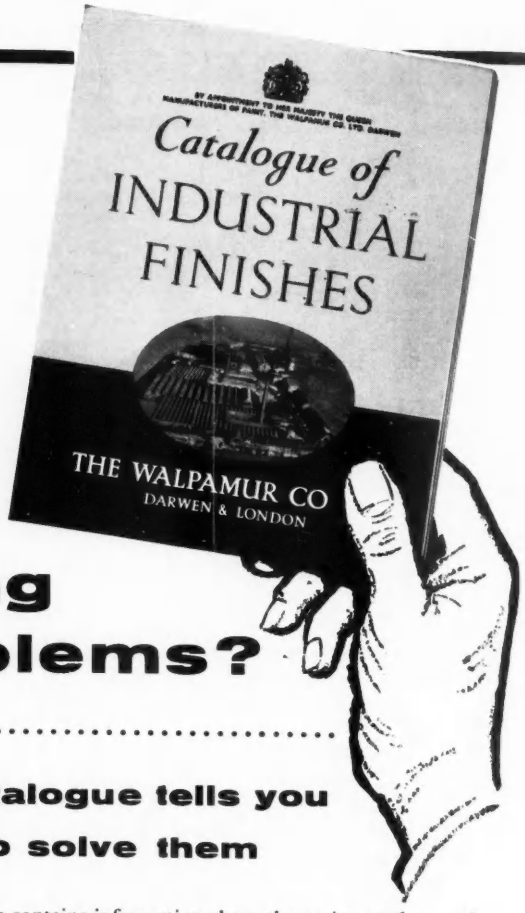

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This FREE catalogue tells you how to solve them

This catalogue contains information about the variety and uses of industrial finishes made by The Walpamur Company Limited, many of which are specially effective in the prevention and control of corrosion of industrial steelwork and plant. Comprehensive data is given regarding the applications and performances of primers for metal, primer fillers and stoppers, low bake and special stoving finishes, quick-drying enamels, and nitro cellulose finishes for wood and metal. Booklets about FEROX Epoxy Resin Paints and Silicone Paints, containing a wealth of information and examples of their uses, and a new Industrial Shade Card showing the full range of colours, are also available on request.

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THE WALPAMUR COMPANY LIMITED
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Paints, enamels, varnishes and finishes for every industrial need

Sir Kelvin Spencer has been appointed a director of the National Carbonising Company Limited and of the Rexco Research & Development Company Limited.

Mr. G. P. Norton has been appointed chairman and **Mr. H. F. Sherborne** vice-chairman of The Yorkshire Copper Works (Holdings).

Mr. J. McBride and **Mr. J. W. Shearer** have been appointed to the board of Lambhill Ironworks Limited.

BUSINESS NOTES

In line with their policy of fostering trade in overseas countries by full co-operation where governments desire to develop indigenous manufacture, **F. Perkins Ltd.**, of Peterborough, following an agreement between them and **Murray Simonsen, S.A.**, the well-known Brazilian organization, have formed a new company, **Motores Perkins S.A.**, for the manufacture in Brazil of the Perkins B340 6-cylinder diesel engine for 5- to 8-ton trucks produced in Brazil and for other applications. Production of this engine is scheduled to start during the second half of 1960 and is expected to reach an annual production of 20,000 engines during 1962.

To establish a closer relationship with its customers, **The General Electric Co. Ltd.** has formed a new sales and distribution area office at Magnet House, Hanger Lane, Ealing, W.5 (Tel.: Perivale 6691), which will cover North London and the Eastern and Southern Counties, including the existing G.E.C. Branches at Ipswich, Dagenham, Luton, Reading, Southampton, and Bournemouth.

Birfield Industries Ltd. announce that the special plant and equipment of **The Phosphor Bronze Co. Ltd.**, of Birmingham, will be transferred to other plants belonging to the Birfield Group.

Expandite Limited announce that they have acquired the whole of the share capital of **Sealanco (St. Helens) Limited,** manufacturers of putties, mastics, glazing compounds, and adhesives.

Elliott Brothers (London) Ltd. have secured from the **Canadian Curtiss-Wright Ltd.** exclusive rights for the manufacture and sales of special nucleonic thickness-measuring apparatus.

The Plessey Company Limited announce that an agreement for the manufacture of "Metallux" resistors in the United Kingdom has been concluded with **Elettronica Metal Lux S.p.a.**, of Milan, Italy.

J. H. Fenner & Company Limited announce the formation in Sydney, Australia, of a company for the manufacture of mechanical power-transmission equipment. The new company is an association between the **Dodge Manufacturing Corporation,** of Mishawaka, Indiana, and the Fenner Company in Hull, and operates in a modern factory of about 20,000 sq ft floor area at Revesby, New South Wales.

With experience in induction heating for industry covering the total range of mains, medium, and radio frequencies, the new **Induction-Heating Division of Garringtons** are now able to offer to customers unique facilities for the design and development of equipment to meet specialized needs in the field of induction applications of surface-hardening and treatment processes, through-heating for forging, extrusion, etc., heating of ingots, blooms, and billets, and melting furnaces. Complete package-type installations can be designed to meet an extremely wide range of industrial requirements, while the constant development of mechanical-handling equipment provides and extends the link between the induction process and the production line, resulting in a specific saving in manpower and handling costs.

Darwins Limited, of Tinsley, Sheffield 9, announce the marketing of a wide range of new products, including rectangular and universal permanent-magnet chucks and tilting adaptor blocks.

Ransome & Marles Bearing Company Limited, of Newark-on-Trent, announce the opening of a new branch office at 42 London Road, Southampton.

G.W.B. Furnaces Ltd., of Dudley, Worcs., have concluded agreements for co-operative manufacture and sale in Great Britain and most of the Commonwealth countries of the whole range of melting plant designed by **Demag-Elektrometallurgie, G.m.b.H.**, of Duisburg, Germany, and by the Lectromelt Furnace Division, McGraw-Edison Company, of Pittsburgh, U.S.A. This agreement enables G.W.B. to offer arc furnaces with a capacity of up to 200 tons with or without rotating shell and alternative electrode control systems. In addition, the agreement covers submerged-arc furnaces for the reduction of ores and the production of ferro-alloys and calcium carbide. Channel-type mains-frequency induction furnaces may also be supplied for melting light metals, copper and copper alloys, zinc, and iron.

George Cohen Sons & Company Ltd. have been appointed by **John Barnsley and Sons Limited,** of Netherton, Worcestershire, as sole agents in Scotland, Ireland, and South Wales for the Barnsley range of electric, overhead-travelling, and goliath cranes.

CONTRACTS

Ashmore, Benson, Pease & Co. Ltd., of Stockton-on-Tees, a member of The Power-Gas Group, have received an order from Colvilles Ltd. for a second blast-furnace plant for their Ravenscraig Works. The furnace will have a hearth diameter of 25 ft 9 in. and will produce over 100 tons of iron per day. The value of the contract is considerably in excess of £1,000,000.

An order worth £300,000 has been placed with Birwelco Limited, and their subsidiary, Brown Fintube (Gt. Britain) Limited, both of Aston, Birmingham, for the supply of 6 Petro-Chem Iso-Flow furnaces and tank heaters at the Rio Duque de Caxias refinery, Brazil, for Petroleo Brasileiro, S.A.

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MONEL 'ANCHORFAST' NAILS

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HOLDS LIKE A SCREW!

An entirely new introduction. Monel 'Anchorfast' nails have most of the advantages of screws for fixing, but can be used as easily as nails. They are so designed that when driven into wood, the grooves in the nail shape the wood fibres into scores of tiny wedges which grip the fastening so tightly that vibration cannot shake it loose.

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100 ton, 4 motor, Overhead Electric Travelling Crane, x 92'-0" span, at Bold "B" Power Station. Photograph by courtesy of the Northern Project Group of the Centrol Electricity Generating Board.

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SOUTH-WEST : R. C. Collins, 48 Westbourne Road, Penarth, Glamorgan. — Phone: Penarth 58527. Grams: Penarth 58527.
NORTHERN IRELAND : General Engineering Products Ltd., 7-9 Great Patrick Street, Belfast. — Phone: Belfast 23743. Grams: Belfast 23743.
REPUBLIC of IRELAND : Charles Nolan & Co., 2 Parker Hill, Lower Rathmines Road, Dublin. — Phone: Dublin 93510. Grams: Dublin 93510.
CANADA : Marshall Equipment Co. Inc., P.O. Box 28, 69 O'Connor Avenue, Dorval Station, P.Q. — Phone: Melrose 1-3528. Grams: Marquipco, Montreal.
Gordon Russell Ltd., 1661 West Fifth Avenue, Vancouver 9, B.C. — Grams: Rustle.
Mumford, Medland Ltd., 576 Wall Street, Winnipeg, Manitoba. — Grams: Mandem.
SOUTH AFRICA : Kenneth Ray Ltd., P.O. Box 5662, 34 Ameshoff Street, Braamfontein, Johannesburg. — Phone: 37-1180, 37-1187-1188-1189. Phone: 44-2168. Grams: Gemray.

REPRESENTED IN PRINCIPAL COUNTRIES THROUGHOUT THE WORLD

An order worth about £1,800,000 for 92 submerged two-way repeaters and 11 submerged equalizers for the transatlantic section of the Commonwealth round-the-world telephone cable, has been placed by Cable and Wireless Ltd. with Standard Telephones and Cables Ltd., of London.

The largest single order for main-line diesel-electric/locomotives yet placed with a private firm by the British Transport Commission has been awarded to the Brush Electrical Engineering Co. Ltd., a member of Hawker Siddeley Industries Ltd. The order is for a further seventy-five Type-2 locomotives, developing 1365 hp and capable of a top speed of 90 mph. Total orders received by the company from the British Transport Commission now number 155 locomotives, all of which are to be delivered before the end of 1960.

The South of Scotland Electricity Board have ordered six buried-type distribution transformers from Ferranti Limited for installation in the Clyde sub-area.

Ruston & Hornsby Ltd. have received a contract worth approximately £300,000 from the Air Ministry for the supply of a number of 410-kW diesel generating sets. The electrical generators of these sets are driven by vee-form 580-bhp diesel engines, built by Rustons' associate company, Davey, Paxman & Co. Ltd.

Heenan & Froude Limited, of Worcester, are to supply a 30,000-bhp hydraulic dynamometer to Burmeister & Wain, of Copenhagen. The dynamometer, weighing about eighty tons, will be the largest and most powerful in the whole of Scandinavia, and will be used for testing a new marine diesel engine.

As part of a planned extension of their resources for the production of medium-width strip, Steel, Peech & Tozer, a subsidiary company of the United Steel Companies Limited, have placed an order with Davy and United Engineering Company Limited for a new cold strip mill for their Brinsworth plant.

An order worth £20,000 has been received by the Gresham Transformer Group, of Hanworth, Middlesex, from the Ministry of Works of H.M. New Zealand Government for eight 1667-kVA, 33-kV single-phase transformers.

NUCLEAR PROPULSION FOR SHIPS

A consortium consisting of Mitchell Engineering Ltd., of London, the Fairfield Shipbuilding and Engineering Company Ltd., of Glasgow, and Combustion Engineering Inc., of New York, have designed a nuclear propulsion system for ships. This system is based on a boiling-water type nuclear reactor, which is available in two versions, giving outputs of 25,000 and 50,000 shp. The smaller unit will be sufficient to propel a cargo vessel of up to 100,000 tons displacement, while two of the larger units can propel a large liner.

DEMONSTRATIONS OF THE DOWTY "TRANSMATIC" TRANSMISSION

In the survey of Hydraulic Variable-Speed Drives in our July, 1958, issue, details were included of the Dowty "Transmatic" hydrostatic transmission as applied experimentally to a standard Fordson "Major" tractor. Since then, progress in the development of this transmission has been rapid, so much so that a public demonstration of this drive was given on May 26 by Dowty at their works in Ashchurch, Gloucestershire, not only in connection with the tractor, but also with respect to its application in a 13-ton diesel "Highwayman" road-roller produced by Marshall Sons & Co. Ltd., of Gainsborough, and in a 50-hp type 48 DH narrow-gauge diesel locomotive made by Ruston & Hornsby Ltd., of Lincoln.

In all cases, the ability of the drive to cope smoothly and easily with varying conditions of load, etc., including extremely steep gradients, was convincingly demonstrated, as well as providing ample proof of its remarkable flexibility, versatility, and ease of operation. In this connection, it should be noted that, with the "Transmatic" drive, the engine can be set to its optimum speed and the exact ratio selected and varied merely by moving a single control lever to suit changing loads. The engine can therefore always operate at the fastest speed consistent with the load, enabling more useful work to be obtained from the same engine power. Furthermore, the ease of operation of the servo-assisted control lever, which is of a simple "straight-through" type with a central neutral position and providing infinitely variable speed ratios in both forward and reverse directions merely by progressively pushing it forward or pulling it back, facilitates manoeuvres and reduces driver fatigue.

NEW METALASTIK OFFICE AND RESEARCH BUILDING

Combining purely functional design and requirements with genuine aesthetic appeal, the new office and research building of Metalastik Ltd., Leicester, is a striking example of what can be accomplished by intelligent co-operation between architect and manufacturer. It is unfortunately all too common to find that newly erected industrial buildings in old built-up areas are either too geometrically monotonous or too flamboyant. No such criticism can be levelled against this new Metalastik building.

Equipped to evaluate the engineering properties of rubber and rubber-bonded units, the Research Department in the building enables measurements and tests to be carried out on standard testpieces and on actual production components, in order to establish design data for the numerous natural and synthetic-rubber compounds developed by the company. For this purpose, the department has a wide range of fatigue-testing machines, and vibration- and shock-measuring equipment, coupled with a wide experience in diagnosing vibration problems. Apart from development work, the department tests and records the properties of all components manufactured by the company and is responsible for devising the control tests necessary to ensure the uniformly high quality of their products.

CONFERENCE ON X-RAY ANALYTICAL METHODS

A conference will be held on X-ray diffraction and spectrography in conjunction with the Department of Chemistry, Imperial College of Science and Technology, from July 6 to 10, 1959. The conference will discuss techniques and instrumentation for diffractometry and fluorescent analysis. Full information concerning the conference, together with details of the registration fees, may be obtained from the Conference Secretary, Research and Control Instruments Ltd., 207 King's Cross Road, London, W.C.1.

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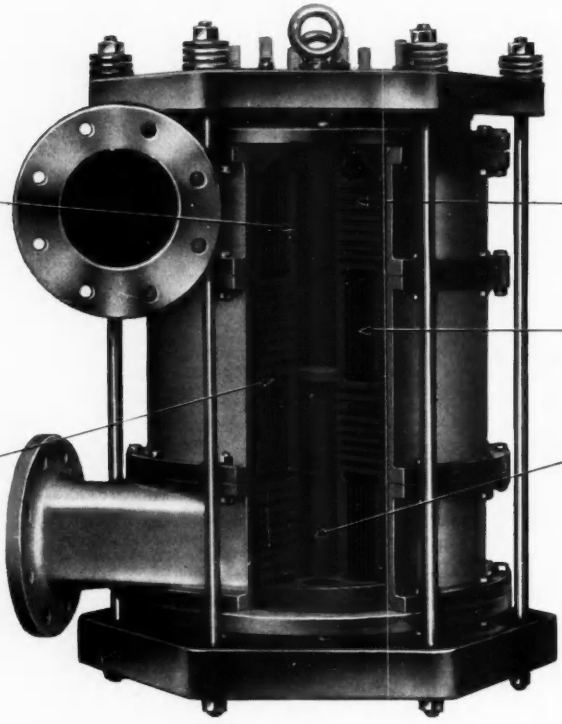

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Induced turbulence inhibits film and scale formation; minimises cleaning.

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NEW LABORATORY OF BRITISH ROLLING MILLS LIMITED

The opening of a new laboratory by British Rolling Mills Limited, of Tipton, Staffs., for the chemical and physical testing of steel, marks an important step in the modernization and expansion programme of the company. Founded in 1914 at Cliveland Street, Birmingham, the company moved to its present site in 1925. Additions have been constantly made to plant and equipment, so that to-day the works consists of three main departments, i.e., the bar shop, where centreless machines and drawbenches are used for the production of bright-drawn bars, the cold-rolling mill, where bright-steel strip is produced in a variety of sizes and qualities, and the recently established plastic-coating shop, where the strip is given a durable and decorative finish by a special plastic-coating process.

NEW AIR-POWER DIVISION OF JOY-SULLIVAN LIMITED

To satisfy the increasing demand for specialized air compressors in a number of industries, Joy-Sullivan Limited, a subsidiary of the Joy Manufacturing Company, of Pittsburgh, Pennsylvania, have formed a new Air-Power Division, with head offices at 7 Harley Street, London, W.1. The division will have manufacturing facilities available at the company's Greenock and Dronfield plants, which were re-organized and modernized during the past few months. Apart from the conventional products of the company, which mainly include mining machinery and equipment, the range of new products offered includes single- and double-drum air hoists and slushers, rock drills, and a series of stationary reciprocating compressors and portable rotary compressors, the latter being powered by British-built Cummins or Rolls-Royce diesel engines. In addition, heavy-duty oil-free compressors will also be produced for the chemical and processing industries, which require compressed air free from hydrocarbon contamination.

RESEARCH IN IRON AND STEEL

The range of new research projects described in the recently published annual report of The British Iron and Steel Research Association includes the application of closed-circuit television to the accurate measurement of the dimensions of hot-forging stock, the use of radar in studying the stockline contour of blast furnaces, and of radioactive isotopes as tracers in the study of diffusion and mixing in slag layers. Some developments are closely related to the manufacture of steel sheet, in which field B.I.S.R.A. initiated the " Plasteel " process, which provides a special plastic coating for steel strip, while other developments aim at improving the efficiency of tandem mills, of the annealing process, and of the methods of application of curing lacquers. Furthermore, considerable advance has been made in developing instruments for speeding up the automation of the iron and steel industry.

Classified Advertisements

The rate for all classified advertisements is 9d. per word : in bold print 1s. per word : minimum order 10s. Box-number advertisements 1s. extra. Semi-displayed advertisements on this page 60s. per single column inch. Instructions, together with remittance, must be received not later than the 1st of each month for advertisements to appear in the same month's issue.

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Wanted. Representatives for correspondence abroad, high earnings, written instructions. Write: Fortuna Publishing Co., Vienna 1/8, Postfach 49.

SECTION ROLLING MACHINES FOR SALE

ROBERTSON 7-STAGE SECTION FORMING MACHINE with additional curving unit. Specially suitable for profiling and bending stainless steel sections. Drive is by 20 h.p. motor through 3-speed gearbox. Diameter of roller shafts, 2 in. Length of shafts available for forming rollers 8½ in. Rolling speeds with 6 in. diameter rollers, 40, 80 and 120 ft. per minute. Weight about 11¼ tons. Full details and illustrations from F. J. EDWARDS LIMITED, 359-361 Euston Road, London, N.W.1 or 41 Water Street, Birmingham 3.

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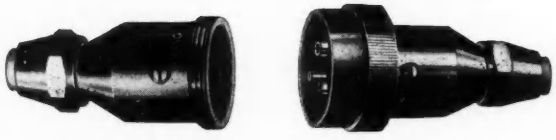

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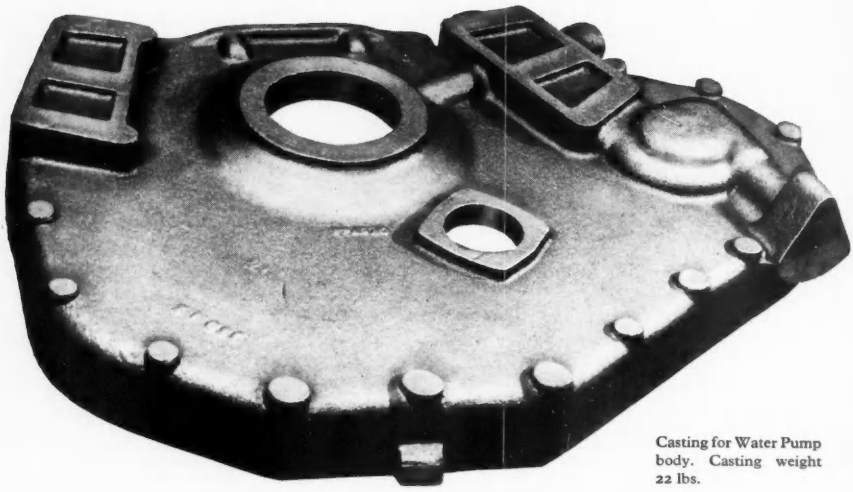

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NEW TECHNICAL BOOKS

Fundamentals of Radio Telemetry. By Marvin Tepper. 126 pp., 85 illustrations. Publishers: John F. Rider Publisher, Inc., 116 West 14th Street, New York 11, N.Y. Price: $2.95.

While it is true that several books have been published on the subject of telemetry, they have usually assumed that the reader is reasonably well-versed in the subject to begin with and include considerable mathematical and theoretical detail. Mr. Tepper, on the other hand, makes no such assumptions, his aim being to explain the overall picture of telemetry on the basis that readers have no background knowledge, other than a basic knowledge of electronics.

After a brief explanation of the principles of telemetry, the book covers such aspects of the subject as telemetry inside missiles, multiplexing, telemetry receiving stations, recovering and recording data, digital techniques in telemetry, telemetry data reduction, and satellite telemetry (of particular topical interest). In addition, appendices covering telemetry standards for guided missiles and magnetic recorder/reproducer standards, and a comprehensive index are included. Also, as is usual in Rider publications of this type, the use of a large number of pictorial examples and illustrations facilitates understanding of the text, although the latter is itself admirably concise and clear.

First Steps in Heat Transfer.. By James Small, D.Sc., Ph.D., M.I.C.E., M.I.Mech.E. 94 pp., 35 illustrations. Publishers: Blackie & Son Limited, 17 Stanhope Street, Glasgow, C4. Price: 12/6.

Deliberately confining himself to a presentation of the subject in its simplest terms and avoiding confusing refinements, the author of this interesting and useful little volume has obviously had in mind the requirements of student engineers who have not previously tackled the elementary aspects of heat transfer. Thus, a high level of mathematical attainment on the part of the reader is not assumed, and those sections, especially thermal conduction, in which some knowledge of calculus is required, stand by themselves and are not essential to the development of most of the later subject matter in the book. Similarly, while an explanation of non-dimensional parameters and their usefulness in the treatment of convective heat flow is given, no attempt is made to deal with the theory of mathematical similarity as a mathematical exercise by itself.

Processing of Thermoplastic Materials. Edited by Ernest C. Bernhardt, Dr. Ing. 706 pp., 508 illustrations. Publishers: Reinhold Publishing Corporation, New York, and Chapman & Hall, Ltd., 37 Essex Street, London, W.C.2. Price: 146/–.

Covering the subject simply and clearly, and designed to help fill the need for a basic textbook on the processing of thermoplastics, this excellent book reviews the engineering fundamentals on which the design of plastics processing equipment is based and demonstrates the practical applications of these basic concepts to the analysis of thermoplastics processing problems. In essence, the book is intended for engineers, but does not require previous knowledge of plastics-processing technology.

The book is divided into sections, each chapter of which is written by an expert in his particular field. In addition to chapters on the flow behaviour of thermoplastics and on heat transfer and thermodynamics, chapters on applications include such subjects as extrusion, injection-moulding, calendering, mixing and dispersing processes, sheet-forming, the forming of hollow articles, and the sealing and welding of plastics. In addition, an unusually comprehensive list of the processing properties of virtually all types of resins manufactured by different firms is given in the form of graphs.

This book is the second in a series of volumes on plastics engineering sponsored by The Society of Plastics Engineers, Inc. The first in the series, " Quality Control for Plastics Engineers ", edited by Lawrence M. Debing, was published in 1957.

The Wiener-Hopf Technique. By B. Noble. 256 pp., 10 illustrations. Publishers : Pergamon Press Ltd., 4 and 5 Fitzroy Square, London, W.1. Price: 65/–.

Fundamentally concerned with methods based on the Wiener-Hopf technique for the solution of partial differential equations, this interesting book (Vol. 7 in the International Series of Monographs on Pure and Applied Mathematics) provides a comprehensive summary of what can be done by this technique at the present state of knowledge. In addition, particular attention is drawn to the various methods of obtaining approximate solutions to problems and to the remarkable range of apparently unrelated topics covered by ramifications of the technique.

The Wiener-Hopf technique was invented in about 1931 to solve an integral equation of a special type, but it was noted during World War II by two independent investigators that problems involving diffraction by semi-infinite planes could be formulated in terms of integral equations which could be solved by this technique, the solution depending on the use of Fourier integrals to obtain a complex variable equation which is solved by analytic continuation. Most of the present book is based on a different, but equivalent, approach, in which Fourier transforms are applied directly to the partial differential equations, and the complex variable equation is obtained directly without the need for formulating an integral equation. From this point of view, the Wiener-Hopf technique provides a significant and natural extension of the range of problems that can be solved by the use of Fourier, Laplace, and Mellin transforms.

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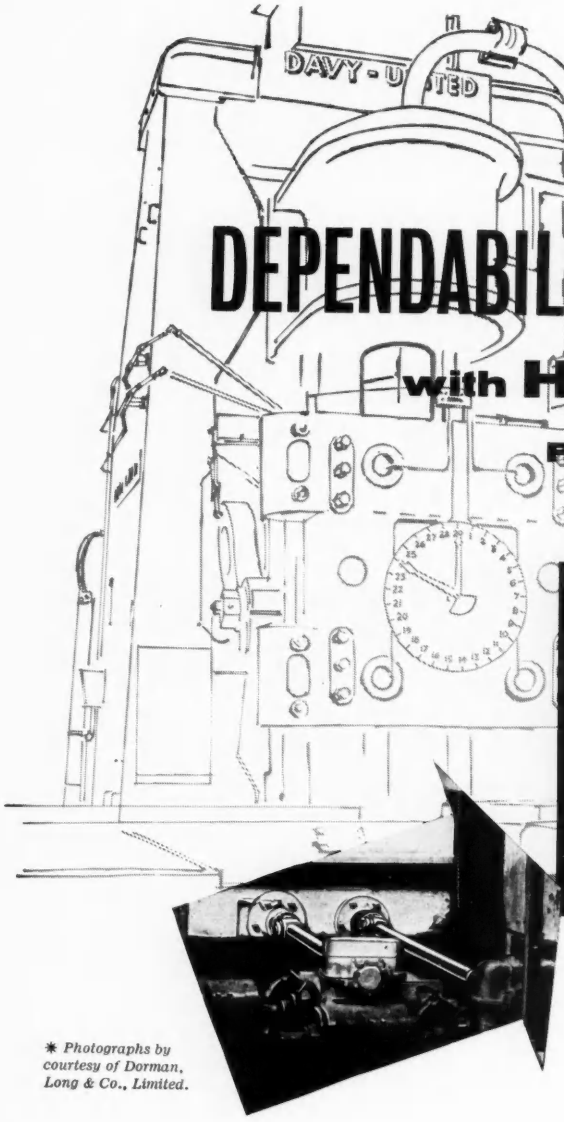

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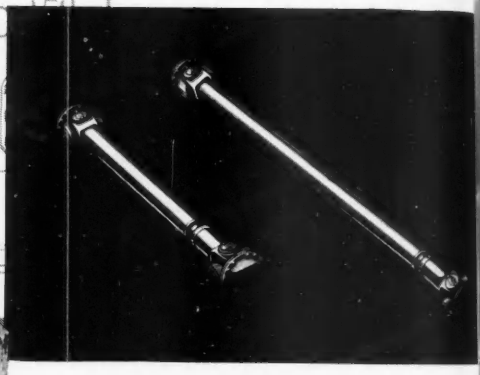

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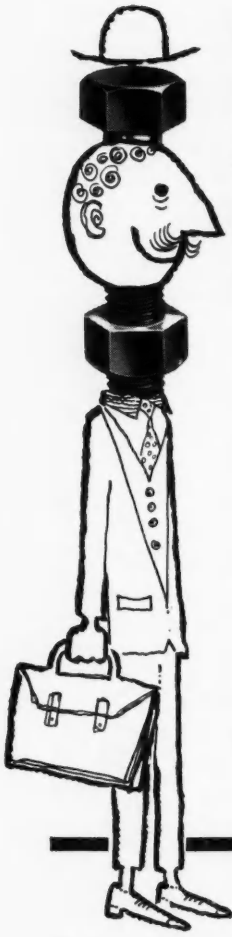

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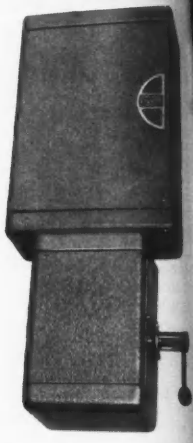

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